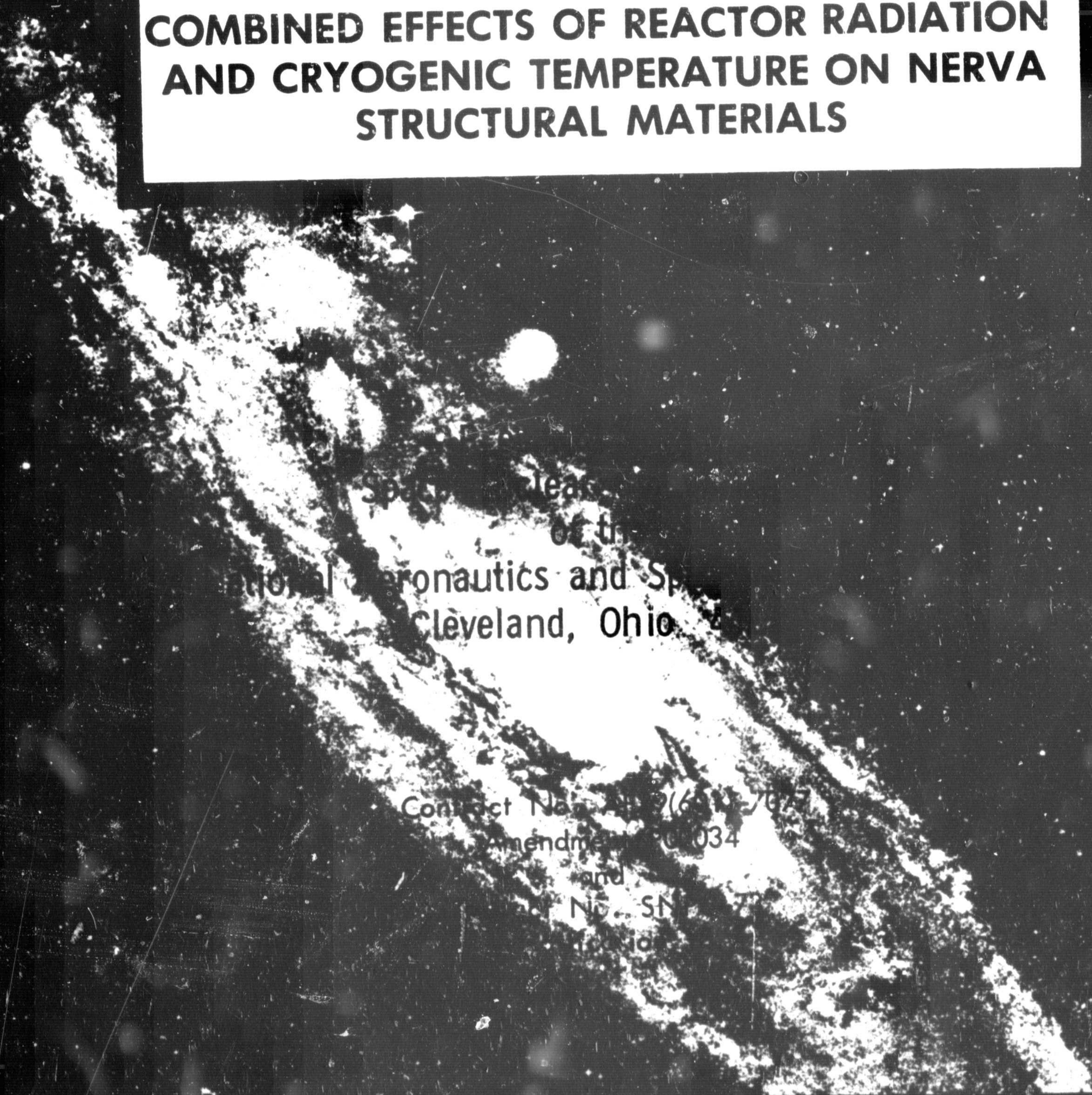
NERVA IRRADIATION PROGRAM

GTR 23 - VOLUME I

COMBINED EFFECTS OF REACTOR RADIATION AND CRYOGENIC TEMPERATURE ON NERVA STRUCTURAL MATERIALS



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GTR 23 - VOLUME I

COMBINED EFFECTS OF REACTOR RADIATION AND CRYOGENIC TEMPERATURE ON NERVA STRUCTURAL MATERIALS

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FOREWORD

GTR-23 is the last in a series of radiation effects tests performed for NASA's NERVA program at the Nuclear Aerospace Research Facility (NARF) at the Fort Worth operation of Convair Aerospace Division of General Dynamics Corporation. Previous tests in this series span ten years and are described in General Dynamics' reports.

The NERVA program is administered by the joint NASA/AEC Space Nuclear Systems Office. At the initiation of GTR-23, Aerojet Nuclear Systems Company was the prime contractor for developing the NERVA engine, and Westinghouse Astronuclear Laboratory was responsible for developing the nuclear reactor. These companies and the Los Alamos Scientific Laboratory (LASL) provided the test specimens and test specifications for GTR 23. The realignment of the NERVA program has shifted Aerojet's and Westinghouse's tasks to LASL which will now receive and analyze all of the GTR-23 test results.

Volume II of this report describes the irradiation and testing of the electronic components included in GTR 23.

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SUMMARY

Specimens fabricated from structural materials that were candidates for certain NERVA applications were irradiated in liquid nitrogen, liquid hydrogen, water, and air. The specimens irradiated in LN_2 were stored in LN_2 and finally tested in LN_2, or at some higher temperature in a few instances. The specimens irradiated in LH_2 underwent an unplanned warmup while in storage so this portion of the test was lost; some specimens were tested in LN_2 but none were tested in LH_2.

The test specimens and test specifications were provided by Aerojet Nuclear Systems Company and Westinghouse Astronuclear Laboratory. However, with the termination of these companies' participation in the program, the Los Alamos Scientific Laboratories has been designated as the recipient of the raw data and untested specimens.

The Ground Test Reactor was the radiation source. The test specimens consisted mainly of tensile and fracture toughness specimens of several different materials, but other types of specimens such as tear, flexure, springs, and lubricant were also irradiated. Tables S-1, S-2, and S-3 list the materials and give information pertinent to the test.

Table S-1
MATERIALS TENSILE TESTED, TEST CONDITIONS, AND PERCENT CHANGE IN PROPERTIES WITH SIGNIFICANCE TEST

Material	Type Specimen	Exposure[a] E > 1 MeV (n/cm^2)	Temp Irrad/test (°R)	No. Specimens Cont/Irrad	% Change (Irrad - Control) at Same Test Temp Yield	Elong	Area Reduct	Text Ref Page
Ti 6Al 4V (Sheet)	Flat tensile Unwelded	3.05 (16)	140/140	3/3	2.1*[b]	-9.2	-4.6	5-3
		4.70 (17)	140/140	3/3	4.8*	-25.2	1.1	
		4.70 (17)	140/540	3/2	2.6	-9.9	2.8	
		4.70 (17)	140/140[c]	3/3	0.05	-18.9	-23.4	
		1.52 (17)	550[d]/140	3/3	2.0*	0.97	28.0	5-4
		1.20 (18)	550[d]/140	3/3	2.8*	1.5	20.6	
		1.52 (17)	550[d]/540	3/3	0.25	-1.6	1.4	
		1.20 (18)	550[d]/540	3/3	4.0*	-14.1	-3.5	
Ti 6Al 4V (Plate Welded)	Flat tensile	3.05 (16)	140/140	5/5	0.33	-9.3	32.5	5-5
		4.7 (17)	140/140	5/5	2.5*	-31.3*	-56.4*	
18 Ni Maraging Steel (Plate)	Buttonhead (Two lots)	9.0 (16)	140/140	2/2	-0.03	16.7	17.0	5-6
		1.66 (18)	140/140	2/2	1.9	20.0*	7.7	
		1.03 (17)	140/140	2/2	-0.60	-6.2	2.3	
		1.78 (18)	140/140	2/2	1.9	-29.2*	-4.1	
Al 7075-T73 (Forging)	Buttonhead	3.00 (17)	140/140	4/4	9.7*	4.2	2.2	5-7
		3.73 (18)	140/140	4/4	20.3*	-7.6	36.1*	
AISI 9310 Steel (Bar)	Buttonhead	2.80 (16)	140/140	2/3	2.4*	-9.5	0.84	5-8
		3.00 (17)	140/140	2/3	1.7*	-8.8	19.8*	
ARMCO 22-13-5 (All weld)	Buttonhead	3.00 (17)	140/140	0/3	-	-	-	5-9
		3.70 (18)	140/140	0/3	-	-	-	
ARMCO 22-13-5 (Plate)	Buttonhead	8.92 (17)	140/140	3/3	13.6*	-24.4	-16.2	5-10
		3.70 (18)	140/140	3/3	29.1*	-30.3*	-17.3	
Ti 5Al 2.5 Sn (Forging)	Buttonhead Unnotched	1.45 (18)	140/140	9/9	13.4*	-63.7*	-14.5*	5-11
		3.77 (18)	140/140	9/9	18.0*	-67.4*	-16.9*	
Ti 5Al 2.5 Sn (Forging)	Buttonhead Notched	1.46 (18)	140/140	8/7	-3.3	(Fracture stress)		5-13
		3.85 (18)	140/140	8/8	-14.2*	(Fracture stress)		
Hastelloy X (Bar)	Buttonhead Unnotched	1.43 (18)	140/140	8/9	66.0*	-15.4*	-3.9	5-16
		4.25 (18)	140/140	8/9	92.4*	-30.1*	-7.1	

Table S-1

MATERIALS TENSILE TESTED, TEST CONDITIONS, AND PERCENT CHANGE IN PROPERTIES WITH SIGNIFICANCE TEST (Cont'd)

Material	Type Specimen	Exposure[a] E >1 MeV (n/cm^2)	Temp Irrad/test (^oR)	No. Specimens Cont/Irrad	% Change (Irrad - Control) at Same Test Temp Yield	Elong	Area Reduct	Text Ref Page
Hastelloy X (Bar)	Buttonhead	1.44 (18)	140/140	8/8	31.6*	(Fracture stress)		5-18
	Notched	4.29 (18)	140/140	8/8	47.1*	(Fracture stress)		
Al 6061-T61	Buttonhead	1.41 (18)	140/140	8/8	31.4*	-38.3*	-11.3	5-21
	Unnotched	4.44 (18)	140/140	8/9	45.9*	-65.4*	-23.8*	
		7/75 (17)	140/340	2/2	13.3	-6.8	-1.3	
		7.40 (17)	140/540	2/2	-1.2	5.5	1.2	
Al 6061-T61	Buttonhead	1.41 (18)	140/140	7/8	14.5*	(Fracture stress)		5-23
	Notched	4.46 (18)	140/140	7/8	20.6*	(Fracture stress)		
Al 5086-H-34 (Sheet)	Flat	3.90 (17)	140/140	3/3	39.1*	-28.9*	-5.2	5-25
	Unwelded	1.84 (18)	140/140	3/3	63.2*	-61.2*	-23.6*	
		3.90 (17)	140/340	3/3	18.5*	-7.6	6.3	
		1.84 (18)	140/340	3/3	29.5*	-24.1*	-1.5	
		3.90 (17)	140/540	3/3	1.3	7.8	59.0*	
		1.84 (18)	140/540	3/3	44.8*	-5.9	8.6	
		3.90 (17)	140/740	3/4	-0.28	32.0*	9.7	
		1.84 (18)	140/740	3/3	-2.49	6.9	15.6*	
Al 5086-H-34 (Sheet)	Flat	3.90 (17)	140/140	3/3	86.8*	-68.2*	68.0	5-32
	Welded	1.84 (18)	140/140	3/3	114.7*	-79.4*	-0.57	
		3.90 (17)	140/340	2/3	38.8*	-26.1	8.3	
		1.84 (18)	140/340	2/3	56.5	-42.0	2.3	
		3.90 (17)	140/540	3/3	2.2	-46.3*	-11.6	
		1.84 (18)	140/540	3/3	23.0*	-56.8*	-51.0	
		3.90 (17)	140/740	2/3	6.0	144.4	146.2*	
		1.84 (18)	140/740	2/3	10.6	222.2	168.4*	

a. Maximum where different for various specimens in group
b. Asterisk indicates significant change at the 95% confidence level
c. Annealed for 100 min at 540^{o}R
d. Irradiated in water

Table S-2

MATERIALS FRACTURE TOUGHNESS TESTED, TEST CONDITIONS, AND AVERAGED DATA

Material	Type Specimen	Exposure[a] E >1 MeV (n/cm^2)	Temp Irrad/Test (°R)	No. Specimens	K_Q (ksi $\sqrt{in.}$) Ave	Std Dev	% Std Dev	Text Ref Page
Al 6061-T6 (Plate)	Compact tension[b] Fatigue cracked	Control	-/140	3	29.07	4.89	16.8	5-46
		7.10 (16)	140/140	3	32.98	3.46	10.5	
		3.90 (18)	140/140	4	25.46	2.09	8.2	
		Control	-/140	3	27.09	2.38	8.8	
		7.10 (16)	140/140	3	31.51	1.63	5.2	
		3.94 (18)	140/140	4	27.91	2.21	7.9	
Al 6061-T61 (Ring forging)	Compact tension Fatigue cracked	Control	-/140	2	26.31	2.41	9.1	5-47
		2.00 (17)	140/140	3	26.19	3.03	11.6	
		8.78 (17)	140/140	2	24.12	1.08	4.5	
		3.77 (18)	140/140	3	26.17	7.11	27.2	
		Control	-/273	2	30.33	4.61	15.2	
		1.95 (17)	140/273	2	28.53	6.66	23.3	
		8.68 (17)	140/273	2	24.74	2.70	10.9	
		4.05 (18)	140/273	1	33.99	-	-	
		Control	-/406	2	25.32	2.13	8.4	
		1.81 (17)	140/406	2	29.59	5.43	18.4	
		8.00 (17)	140/406	2	23.15	4.40	19.0	
		4.13 (18)	140/406	2	27.21	4.65	17.1	
		Control	-/540	2	28.83	0.24	0.8	
		1.63 (17)	140/540	2	31.66	0.69	2.2	
		6.95 (17)	140/540	3	33.74	1.60	4.8	
		4.09 (18)	140/540	2	31.02	0.54	1.8	
Al 7075-T73 (Forging)	Compact tension[b] Fatigue cracked	Control	-/140	4	28.17	1.40	5.0	5-49
		2.97 (16)	140/140	4	27.20	0.88	3.2	
		4.23 (17)	140/140	4	25.99	1.00	3.8	
		3.16 (18)	140/140[c]	3	27.83	0.29	1.1	
		Control	-/140	4	27.67	0.37	1.4	
		2.92 (16)	140/140	4	27.42	0.41	1.5	
		4.34 (17)	140/140	4	25.82	0.53	2.1	
		3.80 (18)	140/140	2	25.93	1.08	4.2	
		2.53 (18)	140/140[c]	1	26.97	-	-	
18 Ni Maraging Steel (Plate)	Compact tension[b] Fatigue cracked	Control	-/140	5	44.63	6.74	15.1	5-50
		1.05 (17)	140/140	5	42.01	1.60	3.8	
		1.54 (18)	140/140	5	42.66	2.67	6.3	

Table S-2
MATERIALS FRACTURE TOUGHNESS TESTED, TEST CONDITIONS, AND AVERAGED DATA (Cont'd)

Material	Type Specimen	Exposure[a] E >1 MeV (n/cm^2)	Temp Irrad/Test (^oR)	No. Specimens	K_Q (ksi $\sqrt{in.}$) Ave	Std Dev	% Std Dev	Text Ref Page
		Control	-/140	5	35.80	2.40	6.7	
		9.40 (17)	140/140	5	37.42	0.88	2.4	
		1.70 (18)	140/140	5	36.25	2.87	7.9	
SAE 9310 Steel (Bar)	Compact tension[b] Fatigue cracked	Control	-/140	4	38.65	6.41	16.6	5-51
		2.40 (16)	140/140	5	33.56	6.08	18.1	
		4.20 (17)	140/140	5	40.01	2.70	6.7	
		Control	-/140	4	27.49	6.52	23.7	
		2.40 (16)	140/140	5	31.35	7.50	23.9	
		4.30 (17)	140/140	5	34.09	4.33	12.7	
ARMCO 22-13-5 (Plate)	Compact tension Fatigue cracked	Control	-/140	5	85.91	3.88	4.5	5-52
		1.45 (17)	140/140	5	84.54	5.26	6.2	
		2.25 (18)	140/140	5	66.10	3.46	5.2	
		3.40 (18)	140/140	5	63.23	3.04	4.8	
Beryllium	WOL Fatigue cracked	Control	-/140	2	9.83	1.01	10.2	5-54
		3.25 (18)	140/140	2	6.13	1.05	17.2	
		Control	-/540	2	11.34	2.19	19.3	
		3.00 (18)	140/540	1	11.94	-	-	
					K_Q (psi $\sqrt{in.}$)[d]			
ZrC (Plate)	Similar to compact tension Not precracked	Control	-/140	1	442.5	-	-	5-53
		2.89 (18)	140/140	3	310.8	116.6	37.5	
		Control	-/540	2	370.8	14.6	3.9	
		2.61 (18)	140/540	4	393.7	31.4	8.0	
					K_{UQ} (ksi $\sqrt{in.}$)[e]			
Ti 6Al 4V (Plate welded)	Center cracked sheet	Control	-/140	4	63.75	2.32	3.6	5-59
		3.33 (16)	140/140	5	61.70	1.24	2.0	
		5.81 (17)	140/140	5	52.64	2.03	3.9	
					K_Q (ksi $\sqrt{in.}$)[f]			
Cu B^{10}	Center cracked sheet	Control	-/140	1	7.76	-	-	5-58
		2.29 (18)	140/140	2	19.20	1.11	5.8	
		Control	-/540	1	6.98	-	-	
		2.25 (18)	140/540	3	14.19	1.63	11.5	

Table S-2
MATERIALS FRACTURE TOUGHNESS TESTED, TEST CONDITIONS, AND AVERAGED DATA (Cont'd)

Material	Type Specimen	Exposure[a] E >1 MeV (n/cm^2)	Temp Irrad/Test (°R)	No. Specimens	K_Q (ksi √in.) Ave	Std Dev	% Std Dev	Text Ref Page
CU B[N]	Center cracked sheet	Control	-/140	2	6.78	0.95	14.1	5-58
		2.39 (18)	140/140	2	16.37	2.50	15.3	
		Control	-/540	3	5.93	0.47	8.0	
		2.35 (18)	140/540	3	15.61	1.20	7.7	

a. Maximum where different for various specimens in group
b. Two lots of specimens
c. Annealed for 100 min at 540°R
d. Toughness calculated on basis of ultimate load
e. K_{UO} is calculated at ultimate load using initial crack length
f. K_Q is calculated at 5% offset load using initial crack length

Table S-3

MATERIALS FOR MISCELLANEOUS TESTS, TEST CONDITIONS, AND PERCENT CHANGE IN PROPERTIES WITH SIGNIFICANCE TEST

Material	Type Specimen	Exposure[a] E >1 MeV (n/cm^2)	Temp Irrad/test (^oR)	No. Specimens Cont/Irrad	% Change (irrad - control) at Same Test Temp			Text Ref Page
Al 5086-H-34 (Sheet)	Kahn-type tear				Tear Strength	Energy to Initiate	Energy to Propagate	5-32
	Unwelded	2.95 (17)	140/140	3/3	13.1*[b]	-15.2	-33.3*	
		2.86 (17)	140/340	3/2	2.5*	4.5	7.5	
		2.78 (17)	140/540	4/4	-0.08	18.2	13.3	
	Welded	2.92 (17)	140/140	3/3	40.9*	16.4	-9.9	
		2.84 (17)	140/340	3/3	13.9	-0.45	-0.22	
		2.75 (17)	140/540	4/4	5.3	-21.9	12.0	
	Heat Affected Zone	2.89 (17)	140/140	3/3	38.7*	-5.9	-26.1*	
		2.81 (17)	140/340	3/3	9.5*	0.11	20.5*	
		2.72 (17)	140/540	4/4	2.4	-21.4*	-4.3	
ZrC (Plate)	Flexure (bar)				Max Stress	Deflection		
		2.84 (18)	140/140	4/3	6.3	0.78		5-62
		2.84 (18)	140/540	4/4	-7.4	24.7		
Feuralon, type AW (Sheet)	Round tensile				Max Stress			
	Lot A	4.3(9)rad(C)	140/140	4/4	-13.5*			5-70
		4.3(9)rad(C)	140/540	4/4	-1.0			
	Lot B	4.3(9)rad(C)	140/140	4/4	-8.8			
		4.3(9)rad(C)	140/540	4/4	2.8			
Feuralon, type AW (Sheet)	Flexure (bar)				Max Stress	Deflection		
	Lot A	3.5(9)rad(C)	140/140	5/6	9.0	0.22		5-73
		3.5(9)rad(C)	140/540	7/6	-0.71	-8.4		
	Lot B	3.5(9)rad(C)	140/140	4/4	-10.3	-6.8		
		3.5(9)rad(C)	140/540	4/4	-0.63	-15.9		

a. Maximum where different for various specimens in group
b. Significant change at the 95% confidence level

Table S-1 contains a summary of the tensile test data. The percent change between the average values for irradiated and control specimens tested at the same temperature are tabulated for 0.2% offset yield stress and bench-measured elongation and area reduction. A "t" test was used to evaluate the significance or nonsignificance of the observed differences in the averages. In making the statistical test, a probability of $\alpha = 0.05$ (95% confidence level) was used. Significance at this level is indicated in the table by the asterisk. When the difference is not indicated as being significant, it does not necessarily mean there is no difference; it may only be that the experiment was not sensitive enough to detect the difference if it existed.

Table S-2 gives the averaged fracture toughness data. Because the averages include data from some specimens with invalid fatigue precracks, differences were not taken. The interpretation of these data should include an evaluation of precrack information given in Section 5.3 for each individual specimen.

Table S-3 summarizes the information for a tear test of an aluminum, the flexure test of ZrC, and the tensile and flexure tests of Feuralon. The percent change between averaged

values for irradiated and control specimens are given, and the significance at the 95% confidence level is indicated.

Beryllium-copper Belleville springs were irradiated in LN_2 and A-286 springs were irradiated in LN_2 and in air at 540° and 1200°R. Neither type spring had a significant change in properties as a result of the irradiation.

As a part of Test Plan M-40-1, specimens encapsulated in a 1000-psi hydrogen gas atmosphere were irradiated in LN_2. The Hastelloy X and Titanium 5Al 2.5Sn from the LN_2 irradiation were maintained in LN_2 after irradiation and tested in LN_2 after being removed from the capsules. Averages for properties of encapsulated and unencapsulated specimens at approximately equal fluence groups were compared; 0.2% offset yield, maximum stress, and bench elongation were the properties considered for unnotched specimens, while the maximum stress was used for notched specimens. The encapsulated aluminum specimens were not tested because it was not possible to remove them without extensive damage to the specimens. Statistically significant differences (at the 95% confidence level) were noted for several properties of Hastelloy X, both unnotched and notched. No significant differences were found for the titanium specimens. The results of the analysis are summarized in Table S-4.

Table S-4

EFFECTS OF IRRADIATION IN HIGH-PRESSURE HYDROGEN GAS - TEST PLAN M-40-1
(Some data from Table S-1 included)

Material and Specimen Type	Fluence Group	Properties and Significance								
		0.2% Yield		Sig	Max Stress		Sig	% Bench Elong		Sig
		Encap	Bare	Diff	Encap	Bare	Diff	Encap	Bare	Diff
Hastelloy X Unnotched	Low	121.8	148.3	yes	178.9	208.1	yes	29.3	46.6	yes
	High	143.7	158.6	yes	189.0	193.4	no	22.5	38.5	yes
		Max Stress		Sig Diff						
Notched	Low	249.8	216.2	yes						
	High	254.4	240.4	yes						
		0.2% Yield		Sig	Max Stress		Sig	% Bench Elong		Sig
		Encap	Bare	Diff	Encap	Bare	Diff	Encap	Bare	Diff
Titanium 5Al 2.5Sn Unnotched	Low	202.4	192.6	no	207.1	197.6	no	4.9	2.5	no
	High	210.7	209.9	no	214.8	214.0	no	4.4	3.4	no
		Max Stress		Sig Diff						
Notched	Low	231.5	215.7	no						
	High	205.5	200.6	no						

Actuator lubricant specimens were irradiated in LH_2. The solid-film lubricant used was a proprietary formulation known as "Vac Kote" and was applied by Bell Brothers Research Corporation, Boulder, Colorado.

Sliding wear tests were performed on six irradiated and seven control specimens at $540^{\circ}R$; seven irradiated and six controls were tested at $1000^{\circ}R$. Results of the sliding wear tests (Tables 5-35 and 5-36) showed no significant change in wear life of the lubricant at $1000^{\circ}R$; however, there was a significant improvement in wear life of the irradiated specimens at $540^{\circ}R$.

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Corrections

Page 2 - 8	Labels are inverted on photograph.
Page 5 - 17	Under Neutron fluence 12.6(18) should be 1.26(18)

I. INTRODUCTION

This report documents the results of the irradiation testing of selected structural materials in the experiment designated GTR 23. The tests were performed at the Nuclear Aerospace Research Facility, operated by General Dynamics, in support of the NASA-AEC NERVA program. The components were selected and provided by Aerojet Nuclear Systems Company (ANSC), Westinghouse Astronuclear Laboratory (WANL), and the Los Alamos Scientific Laboratory (LASL).

A total of 805 material specimens were irradiated in liquid hydrogen, liquid nitrogen, water, or air. Prior to the irradiation, a mapping run was performed to ascertain proper specimen locations for the assigned neutron fluences in the LH_2 and LN_2 dewars. The mapping run was made on 17 May 1972 at a power level of 100 kW for one hour.

The 6000-MWh irradiation began 24 May 1972. The test plan called for keeping the specimens in the LN_2 and LH_2 dewars submerged in cryogen from the beginning of the irradiation through postirradiation testing. After 2676-MWh of operation, detonations in the ice that had accumulated on the exhaust line to the LH_2 dewar forced a reactor shutdown and termination of

LH_2 flow. Investigations proved that the detonations were not the result of hydrogen leakage and on 8 June the LH_2 dewar was again filled and the irradiation was resumed.

Shortly after reaching the 10-MW power level ($\sim$45 min), a number of detonations in and around the LN_2 dewar forced another shutdown. Because these detonations damaged the dump valves in the dewar, the dewar was removed from the irradiation cell and the specimens were transferred to holding dewars in the Irradiated Materials Laboratory. The irradiation of all other specimens was resumed on 21 June and concluded on 7 July 1972.

The detonations in the LH_2 exhaust line and LN_2 dewar resulted in deviations from the test plan in that the specimens in LH_2 had a warmup about midway through the irradiation and the specimens in LN_2 received about half of the planned exposure. During the period after the irradiation when the radioactivity of the LH_2 dewar and specimens was decaying sufficiently to enable handling, the liquid hydrogen supply was depleted because of a faulty gage on the supply trailer. As a result of the ensuing warmup, it was decided that the LH_2 specimens would not be tested. Most of these specimens were shipped to the Los Alamos Scientific Laboratories. Tests on the specimens irradiated in LN_2, water, and in air were carried out as planned.

Section II describes the test materials and specimens; Section III outlines the irradiation and dosimetry procedures; Section IV describes the test equipment and methods; and Section V is devoted to the discussion of the individual tests and the presentation of the test results.

II. TEST MATERIALS AND SPECIMENS

Table 2-1 lists the materials irradiated in GTR 23, the type of test, and other pertinent information. Not all of the irradiated specimens were tested at NARF, principally those from the abortive liquid hydrogen test but including some to be tested elsewhere and some destroyed in the LN_2 dewar; these are indicated in the table.

Figures 2-1 through 2-5 illustrate typical specimens of each configuration. The metal tensile specimens (Fig. 2-1) were either flat (gage lengths of 1.0, 1.5, or 2.31 in.) or two styles of round buttonhead (both 1.5-in. gage length); the notched tensile specimens were all of round buttonhead configuration with a notch diameter of nominally 0.18 in.

The fracture toughness specimens (Fig. 2-2) consisted of three sizes of compact tension specimens and one WOL type (Be). The small ZrC specimens and the beryllium specimens had straight machined notches; all other specimens had chevron-style notches. The nominal dimensions (in inches) for the various configurations were as follows (see Fig. 5-1 for a sketch of the compact tension specimen):

Drawing	Length (X)	Width (W)	Thickness (B)
1138365	2.50	2.00	1.00
100E439 H38	2.50	2.00	1.00
1139208	1.875	1.50	0.75
577F544 H14F	0.62	0.50	0.25
100E439 H18	3.20	2.55	1.00

With the exception of the ZrC, all of these specimens were fatigue cracked.

Typical center cracked sheet fracture toughness specimens of titanium and copper-boron are shown in Figure 2-3. The titanium specimens were nominally 3.00 in. wide and 0.20 in. thick. The CuB^{10} sheets were about 3.2 in. wide and 0.1 in. thick and the CuB^{N} sheets were about 3.1 in. by 0.05 in. The actual dimensions of each specimen are given in the data tables of Section 5-3.

Specimens illustrated in Figure 2-4 are the Al 5086-H-34 tear, Feuralon tensile (1.0-in. gage length) and flexure (5.00 in. long, 0.50 in. wide, 0.25 in. thick), fibrous graphite flexure (4.0 in. long, 0.25 in. wide, 0.2 in. thick), Al 7075-T73 adhesion, and the Timken race used in the sliding wear test of the actuator lubricant. Figure 2-5 shows an A-286 spring and a copper-boron Belleville spring.

Available pedigree data for the materials are contained in Appendix A.

Table 2-1

STRUCTURAL MATERIALS IRRADIATED IN GTR 23

Test Sponsor	Test Specification	Material	Type of Test	Configuration Drawing	Irradiation Media
ANSC	M-5-1	A-286 Bolt	Tensile[a]	1118388	LH_2
	M-6-1	Fibrous Graphite	Flexure[a]	1138147	Helium
	M-7-1	Al6061-T6	Fracture Toughness	1138365	LN_2
	M-9-1	Ti 6Al 4V	Tensile	1138194	LN_2 & H_2O
	M-9-2	Ti 6Al 4V	Tensile	1138194	LN_2
	M-9-3	Ti 6Al 4V	Sheet Fracture Toughness	1138226	LN_2
	M-14-1	Feuralon, Type AW	Tensile	1139068	LH_2
	M-14-2	Feuralon, Type AW	Flexure	1138147	LH_2
	M-16-1	18 Ni Maraging Steel	Tensile	1138265	LN_2
	M-16-2	18 Ni Maraging Steel	Fracture Toughness[b]	1139208	LN_2
	M-21-1	Al 7075-T73	Tensile	1138265	LN_2
	M-21-2	Al 7075-T73	Fracture Toughness	1138365	LN_2
	M-21-4	Al 7075-T73	Adhesion[a]	1138310	LN_2 & H_2O
	M-31-1	AISI 9310 Steel	Tensile	1138265	LN_2
	M-31-2	AISI 9310 Steel	Fracture Toughness[b]	1138365	LN_2
	M-38-1	ARMCO Alloy 22-13-5	Tensile	1118388	LN_2
	M-38-3	ARMCO Alloy 22-13-5	Fracture Toughness	1138365	LN_2
	M-38-4	ARMCO Alloy 22-13-5	Tensile	1138265	LN_2
	M-39-1	Be Cu Springs	Spring Constants	N/A	LN_2
	M-40-1	Hastelloy X	Tensile	1138265	LN_2 & LH_2
ANSC	M-40-1	Ti 5Al 2.5Sn ELI	Tensile	1139567	LN_2 & LH_2 [e]
WANL	M-40-1 & RTS-60	Al 6061-T61	Tensile	389D082 H01 389D084 H01	LN_2 & LH_2
	44A004	Bearing Retainers	-[a]	1139961	LH_2
	RTS-56	Actuator Lubricant	Timken Race	N/A	LH_2
	RTS-58	A-286 Springs	Spring Constants	388D992	LN_2, LH_2, & Air
	RTS-61	Al 6061-T61	Fracture Toughness	100E439 H38	LN_2
	RTS-62	Al 5086-H-34	Tensile	100E445 H01	LN_2
	RTS-63	Al 5086-H-34	Tear	100E445 H05	LN_2
	RTS-64	CuB^{10}	Sheet Fracture Toughness	577F686 H03	LN_2
	RTS-65	CuB^{N}	Sheet Fracture Toughness	577F686 H04	LN_2
	RTS-66	ZrC	Flexure	388D613	LN_2
	RTS-67	ZrC	Fracture Toughness	577F544 H14F	LN_2
	RTS-68	A-286	Tensile[c]	609B231	LN_2
WANL	RTS-69	Beryllium	Fracture Toughness[d]	100E439 H18	LN_2

[a]Specimens shipped to LASL for testing.
[b]Some specimens shipped to LASL for testing.

[c]Specimens lost due to detonations in dewar.
[d]Some specimens lost due to detonation in dewar.
[e]Unnotched and notched specimens were irradiated bare in the cryogens and in steel capsules pressurized with hydrogen gas at 1000$\pm$25 psig. The encapsulated specimens were irradiated in LN_2 only.

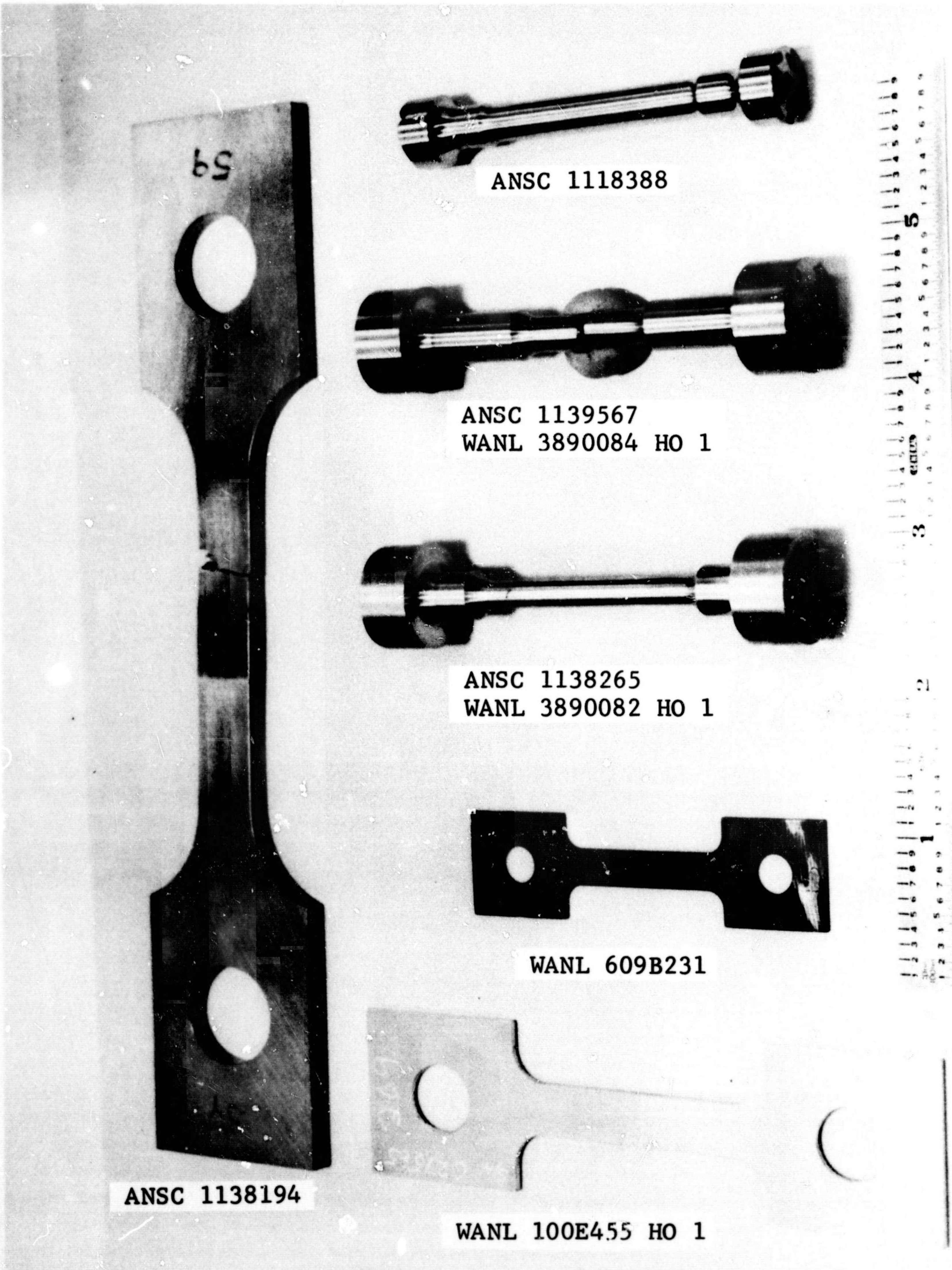


Figure 2-1 Configurations of Tensile Specimens

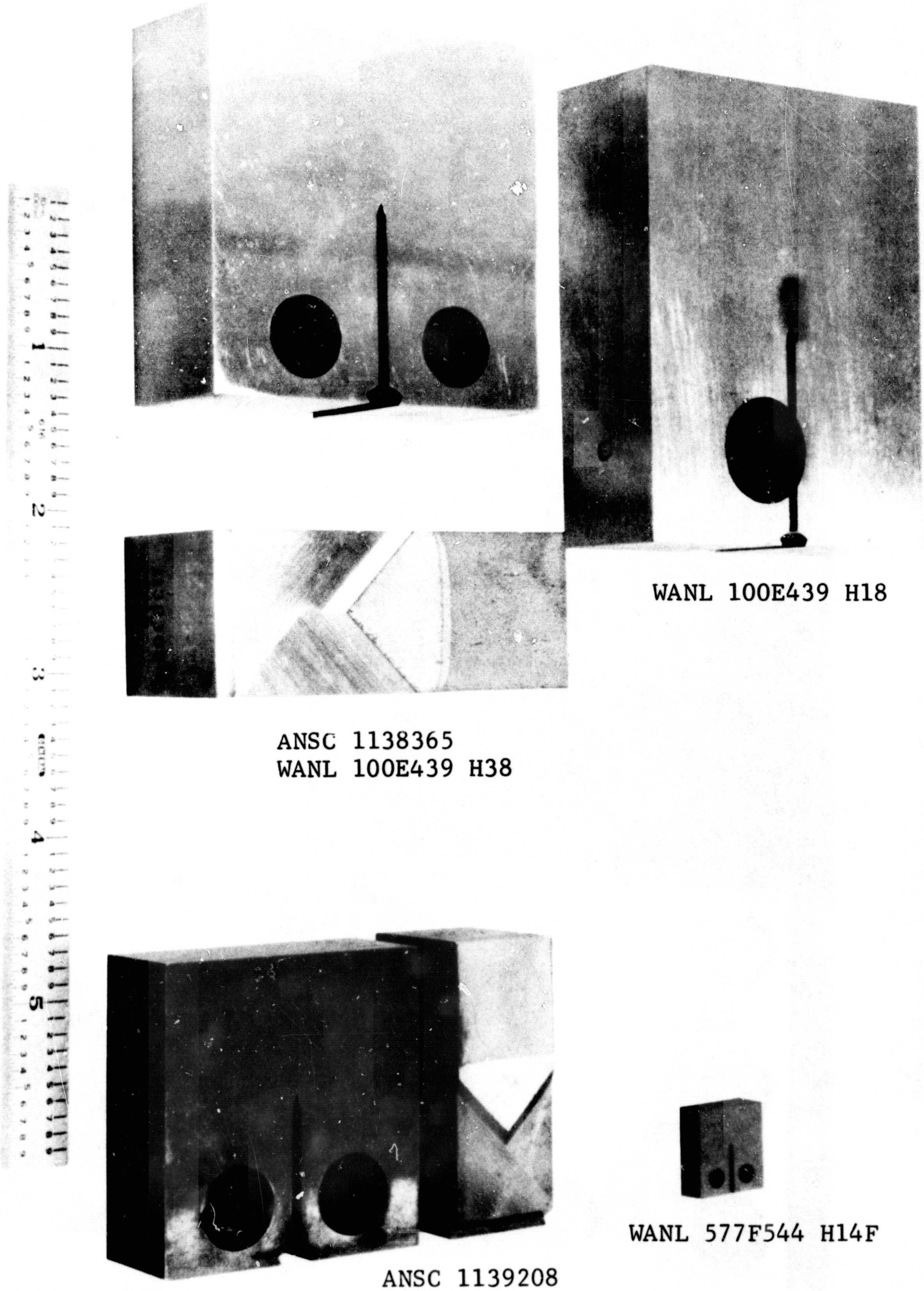
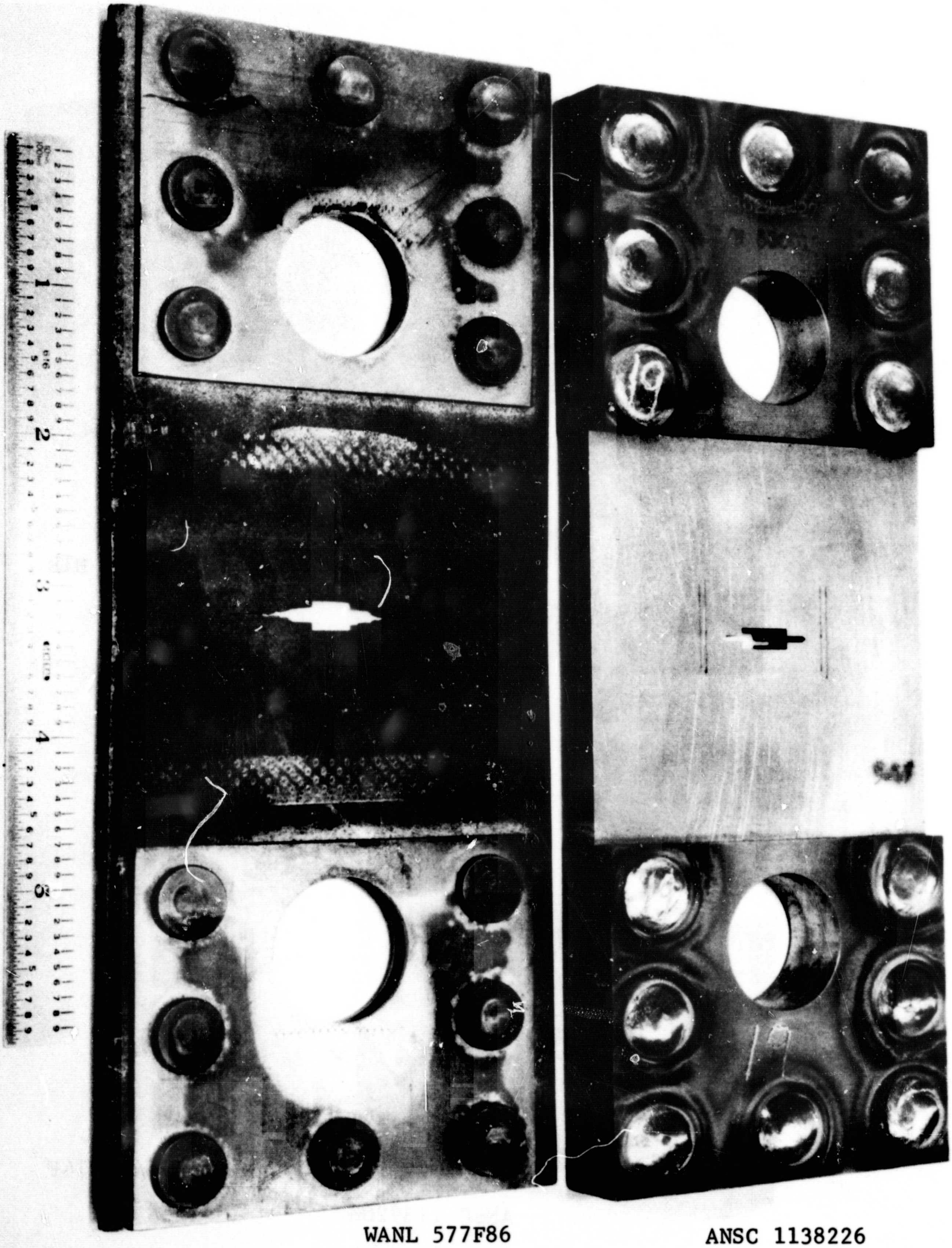


Figure 2-2 Configurations of Compact-Tension Type Fracture Toughness Specimens



WANL 577F86 ANSC 1138226

Figure 2-3 Configurations of Sheet Fracture Toughness Specimens

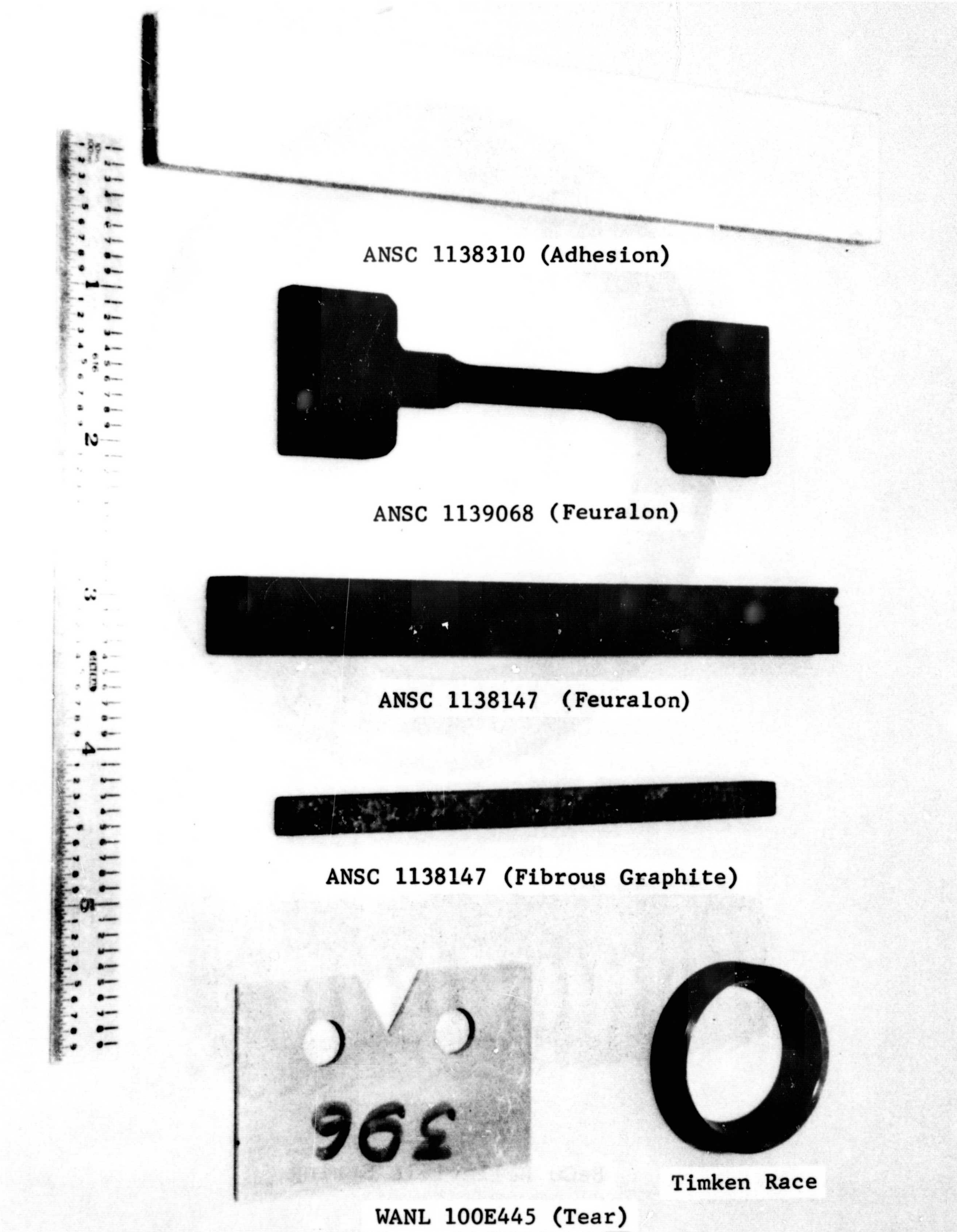


Figure 2-4 Configurations of Miscellaneous Specimens

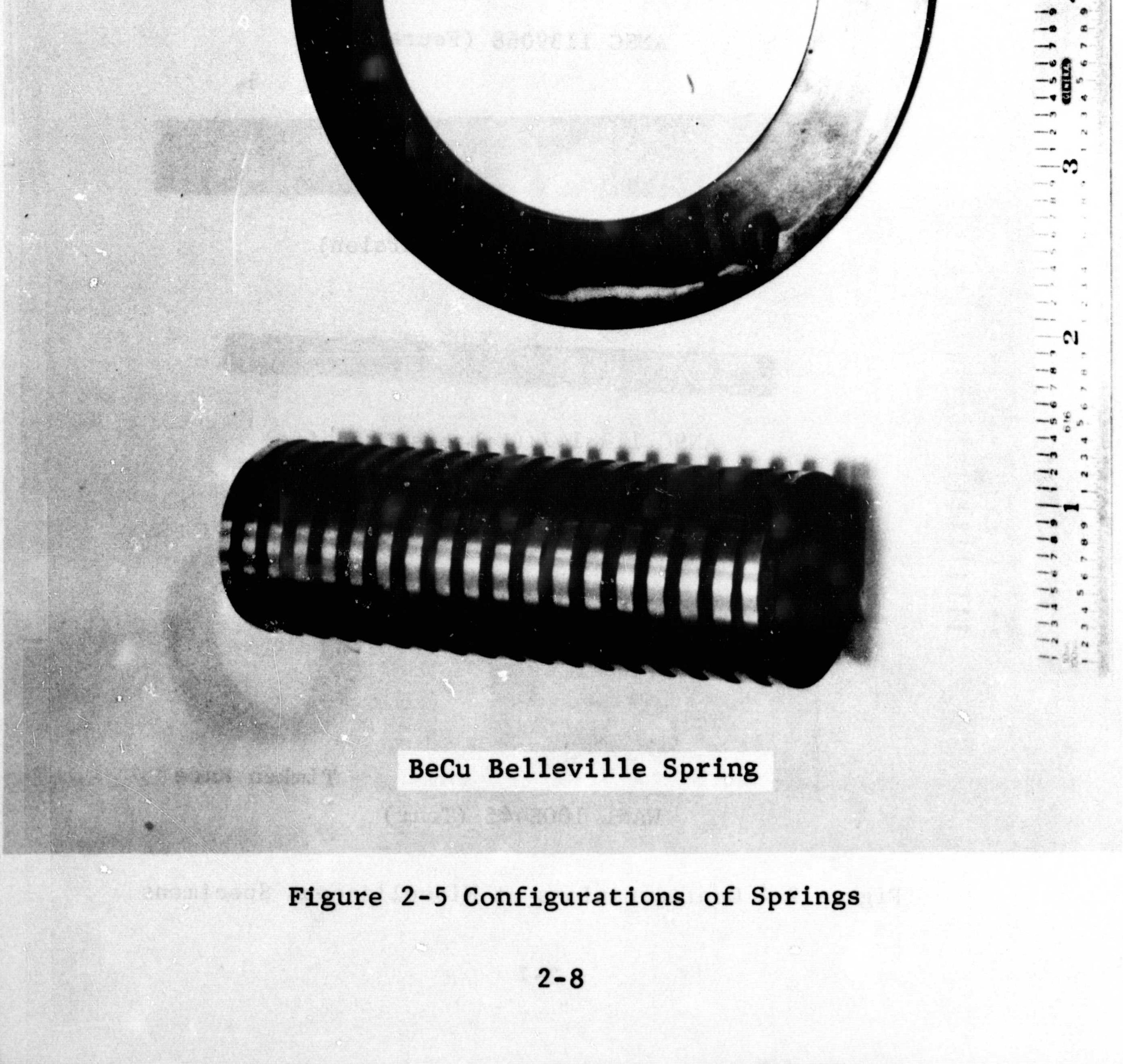


Figure 2-5 Configurations of Springs

III. IRRADIATION PROCEDURES

Test GTR 23 consisted of the irradiation and testing of selected components and structural materials which were irradiated in LN_2, LH_2, water, and air. The fast-neutron fluences required by the ANSC and WANL tests called for an irradiation of 6000 MWh. A separate low-power-level mapping run was made to confirm the correct positioning of the test specimens in the irradiation fixtures.

3.1 Radiation Source

The 10-MW Ground Test Reactor (GTR), which served as the radiation source for this experiment, is a light water-moderated, heterogeneous, solid-fuel reactor. The core contains 33 MTR-type aluminum-clad fuel elements and five control rod assemblies. The core is suspended by an aluminum frame from upper structural members of an aluminum tank. The water-filled tank is located at one end of a below-grade pool leaving a dry irradiation cell at the other end. The reactor is carried by a horizontal positioning mechanism that permits it to be moved into and out of the closet-like structure built into the north wall of the GTR tank. When in the closet, three faces of the core are available for irradiation of test items placed adjacent to the

three sides of the closet - designated east, west, and north. The hydrogen dewar was placed in the east position, the nitrogen dewar in the north position, and the table for components in air in the west position.

The reactor closet is constructed of 1-in. aluminum plate covered (on areas adjacent to the reactor core) by a 20-mil thickness of cadmium to attenuate thermal neutrons. The cadmium extends 36 in. east and west from the closet along the tank wall and 36 in. up and down from the horizontal centerline of the reactor core. The centerline is 59 in. above the irradiation cell floor.

3.2 Irradiation Fixtures

3.2.1 Liquid Hydrogen Dewar

The liquid hydrogen dewar was a double-walled stainless-steel vessel with the annulus evacuated to provide an insulating barrier. Inner dimensions were 24-in. diameter by 40-in. height. The dewar was equipped with two supply lines, one exhaust line, and two liquid level probes. Effluent hydrogen gas was exhausted directly through a port in the dewar lid to an exhaust gas system which carried it to the flare stack where it was burned.

All penetrations through the LH_2 dewar lid were enclosed by an inerting shroud atop the lid. The purpose of the shroud was

to provide an inert atmosphere (gaseous helium) in the immediate vicinity of penetrations at the lid and far enough above the lid to allow the lines and cables to warm to near cell temperature. The shroud was continually purged with helium gas; the outflowing gas was monitored for hydrogen content and exhausted through the GH_2 exhaust system. The seal between the shroud and the dewar lid was a bolted flange with a compressible gasket. Penetrations into the shroud were through welded or bolted flanges for lines and tubing and hermetic connectors for electrical harnesses.

3.2.2 Liquid Nitrogen Dewar

The liquid nitrogen dewar was of similar design to those used previously in tests GTR 20C and GTR 22; it consisted of a removable inner LN_2 container and an outer chamber which maintained a flow of GN_2 around the LN_2 container. The inner container was designed in such a manner that when it was attached to the dewar lid effluent gaseous nitrogen flowed over the front edge (reactor side) of the LN_2 container, down the front face, under the LN_2 container, and back up and out the dewar vents. Barrier plates on either side of the LN_2 container formed the exhaust path for the GN_2. The continuous flow of cold GN_2 provided sufficient cooling of the reactor side of the irradiation dewar to preclude excessive heating. The dewar was equipped

with two LN_2 supply lines, two liquid level probes, two dump valves, and four exhaust tubes.

The pressures and liquid levels in both the LN_2 and LH_2 dewars were monitored and controlled from the Radiation Effects Test System (RETS) Console. The liquid level probes were equipped both with resistors and thermocouples located at predetermined points throughout the depth of the dewar. The resistors were connected to a discrete-level indicator/annunciator panel. The thermocouples were connected, through a switch selector, to Bristol recorder-controllers. The Bristols provide automatic level control at any of the probe thermocouple locations.

Pressures in both dewars and in the shroud of the LH_2 dewar were sensed by 0-15 psig transducers. The transducers were located outside the high radiation field of the GTR cell and were connected to the dewars with copper tubing. The transducer outputs were displayed at the RETS console.

3.2.3 West Table and Water Rack

An open table was installed at the west irradiation position to hold the air-irradiated specimens. The specimens were grouped by target fluence and located accordingly on the table which extended from the closet to the cell wall.

The specimens irradiated in water were installed in a water rack which attached directly to the south face of the GTR frame.

3.3 Dosimetry Procedures

Target neutron exposures for the components were specified as the fluences of neutrons of energy greater than 1 MeV. To arrive at a specimen arrangement for the various irradiation fixtures and then determine by measurement the actual exposure of each specimen required the following steps:

1. Based on data from previous irradiations, a specimen layout based on the required neutron fluences was made for each fixture.

2. Specimen locations were verified or adjusted by use of data from a short-duration mapping irradiation.

3. Neutron fluences received by the specimens during the actual irradiation were measured by means of nickel foils. Conversion factors necessary to convert measured fluences to the proper energy range (E >1 MeV) were based on neutron spectral data obtained in this and previous tests.

Prior to the 6000-MWh irradiation, both dewars and the water rack (but not the air table) were mapped in a one-hour irradiation at a power level of 100 kW. The dewars were filled with cryogen and most of the material specimens were in place, but to avoid possible damage to the electronic components during the subsequent warmup and handling to remove the dosimeters, most

of them were not in place during the mapping. Dosimeters were placed at or near the planned locations, however. Upon completion of the irradiation, which was made on 17 May 1972, the fixtures were removed from the irradiation cell and the dosimetry was retrieved for measurement. Fluxes measured with sulfur pellets ($E > 2.9$ MeV) were converted to fluxes of $E > 1$ MeV and projected to fluences for 6000 MWh. Data from indium foils ($E > 0.85$ MeV) in conjunction with spectral data from previous tests were used to make the energy conversion. The conversion factors ($E > 2.9$ MeV to $E > 1$ MeV) were 2.85 for air and ranged from 2.4 to 3.7 for the LH_2 dewar and from 3.4 to 4.8 for the LN_2 dewar.

Cobalt glass dosimeters were irradiated during the mapping run at some locations of interest. Neutron-to-gamma ratios were then used to estimate total gamma doses.

The fast-neutron fluences received by the test specimens during the GTR-23 irradiation were measured with nickel foils attached to or placed near them. Data from these foils in conjunction with the energy-range conversion factor were used to compute fluences of $E > 1$ MeV.

Table 3-1 gives error assignments for pertinent dosimetry measurements.

Table 3-1

ERROR ANALYSIS OF DOSIMETRY MEASUREMENTS

Source of Error	Accuracy and/or Precision	Basis
Nuclear Measurements		
Neutron detectors (count data)		
. Sulfur E >2.9 MeV	±1%	Estimated from count data obtained in the mapping run.
. Phosphorus E < 0.48 eV	±2%	" "
. Indium E >0.85 MeV	±2%	" "
. Nickel E >2.9 MeV	±1%	Estimated from count data obtained from actual test configuration (6000 MWh).
Weight	±1%	Estimated from sample.
Intercalibration of Counters	±1%	Estimated from counting same foil on each counter.
Gamma (Cobalt Glass)	±3%	Estimated from pairs of Cobalt glass gamma detectors from mapping run.
GTR Spectrum E >1 MeV	±10%	Estimated from threshold detectors - Al, 8.1 MeV; S, 2.9 MeV; U, 1.5 MeV; In, 0.85 MeV; Np, 0.75 MeV; and Pu, 1 keV.
Basic calibration of counters including counting precisions	±5%	Calibrations of counters with: 4 pi counters; beta-gamma coincidence counting and counting standard source techniques.

Table 3-1 (cont'd)

Source of Error	Accuracy and/or Precision	Basis
Extrapolation from mapping run data to measured Ni fluences for specimen irradiation	$\pm 10\%$	Judgment.
Combined (E >1 MeV)	$\pm 15\%$	Root mean square.
Thermal neutron fluence (E < 0.48 eV)	$\pm 7\%$	Estimated by the difference between bare and cadmium covered phosphorus (1/v) detectors which are activated independent of spectrum shape up to cadmium flux. Each detector uncertainty is $\pm 5\%$.
Averaging of fluence for each group of specimen (E < 0.48 eV)	$\pm 5\%$	Used only average fluence for each group of specimen instead of individuals.
Combined (E < 0.48 eV)	$\pm 18\%$	Root mean square: extrapolation from mapping run data, calibration of counters, etc.
Gamma Dose	$\pm 19\%$	Estimated from gamma/neutron ratio obtained from mapping run with cobalt glass gamma detectors and sulfur neutron detectors (2.9 MeV) and measured Ni fluence (2.9 MeV) from 6000 MWh test.

3.4 GTR-23 Irradiation

The 6000-MWh irradiation was started on 24 May 1972 and was concluded on 7 July 1972. A summary of the reactor log is given in Table 3-2. It should be noted that the elapsed time at power includes only the time the reactor was operating in the closet position.

3.5 Postirradiation

The specimens irradiated in LN_2 were stored in LN_2. Those to be tested in LN_2 were transferred to the test apparatus without being removed from the cryogen. Specimens tested at temperatures above $140^{\circ}R$ were transferred from LN_2 to the appropriate temperature control apparatus at the time of the test. At completion of the testing, the specimens were measured and photographed, as specified, or placed in storage until post-test measurements were complete.

The specimens irradiated in LH_2 were removed from the dewar at an appropriate time and placed in storage at ambient temperature until testing or shipment to LASL.

Table 3-2

SUMMARY OF GTR-23 REACTOR LOG

Power Level (MW)	Elapsed Time at Power (h)	Accumulated Exposure (MWh)	Remarks
4	0.33	1.3	
7	0.47	4.6	
10	4.12	45.8	
			GTR scram.
10	24.11	286.9	
			GTR retracted; hydrogen leak on ramp.
1	0.10	287.0	
10	25.97	546.7	
9.2	0.23	548.8	
10	30.92	858.0	
			GTR retracted; electronic components data cycle.
9.5	0.28	860.7	
10	24.40	1140.7	
			GTR retracted; electronic components data cycle.
9.6	0.03	1105.0	
10	20.52	1310.2	
8	0.17	1311.6	
10	9.15	1403.1	
9.1	0.17	1404.6	
10	10.72	1511.8	
			GTR scram.
9.3	0.12	1512.9	
10	116.35	2676.4	
			GTR shutdown; detonations in ice on GH_2 exhaust line.
1	0.06	2676.5	
10	0.78	2684.3	
			GTR shutdown; detonations in LN_2 dewar.
10	3.20	2716.3	
			GTR shutdown; malfunction of irradiation-cell exhaust dampers.
10	217.10	4887.3	
			GTR shutdown; broken air line.
10	6.92	4956.5	
			GTR scram
10	104.45	6001.0	

IV. TEST EQUIPMENT AND METHODS

4.1 Test Equipment

Equipment required for performing specified tests on GTR 23 test specimens included:

1. Tensile test machines and associated components for tension tests and fracture toughness tests at test temperatures called for in the test specifications.

2. Displacement gages for fracture toughness tests.

3. A sliding wear tester for testing an actuator lubricant.

Additional equipment used included an optical comparator for determination of physical dimensions of test specimens before and after testing and a macrocamera with Polaroid attachment for photographing individual specimens.

4.1.1 Tensile Test Machine and Accessories

Three tensile test machines were employed in testing the ANSC and WANL specimens. They were the Model TT-C and Model TT-D Instron machines and the Model 120A Baldwin test machine. The Model TT-C (10,000-lb load capacity) and the Model TT-D (20,000-lb load capacity) Instrons were used for testing of all tensile, fracture toughness, tear, and flexure specimens with the exception of the Ti 6Al 4V fracture toughness specimens which were tested on the Baldwin machine (120,000-lb load capacity).

The cryostat of the type used for immersing ANSC and WANL specimens in LN_2 while being tested is shown installed in the Instron strain frame in Figure 4-1. Figure 4-2 shows the Baldwin tester with cryostat in place. The cryostats were fabricated of urethane foam material. The inner and outer surfaces were coated with successive layers of RTV 102 silicone adhesive and fiberglass cloth, with the final layer of RTV 102.

For WANL tensile and fracture toughness tests at 276°, 340° and 406°R, a double-walled container having small holes in the inner wall was used for temperature control of the test specimen. The container enclosed the grip and specimen section of the Instron load train. Cold nitrogen gas supplied at a controlled rate between the chamber walls flowed over the test specimen and grips. The flow rate of the cold GN_2 was adjusted to keep the specimen at the desired temperature during testing. This double-walled container was also used for annealing of specimens at temperatures between 140° and 540°R. The specimens were suspended in the wire basket within the cylinder wall along with a dummy specimen instrumented with a thermocouple to monitor temperatures during annealing. The flow rate of the cold nitrogen gas was adjusted to keep the specimen at the desired temperature.

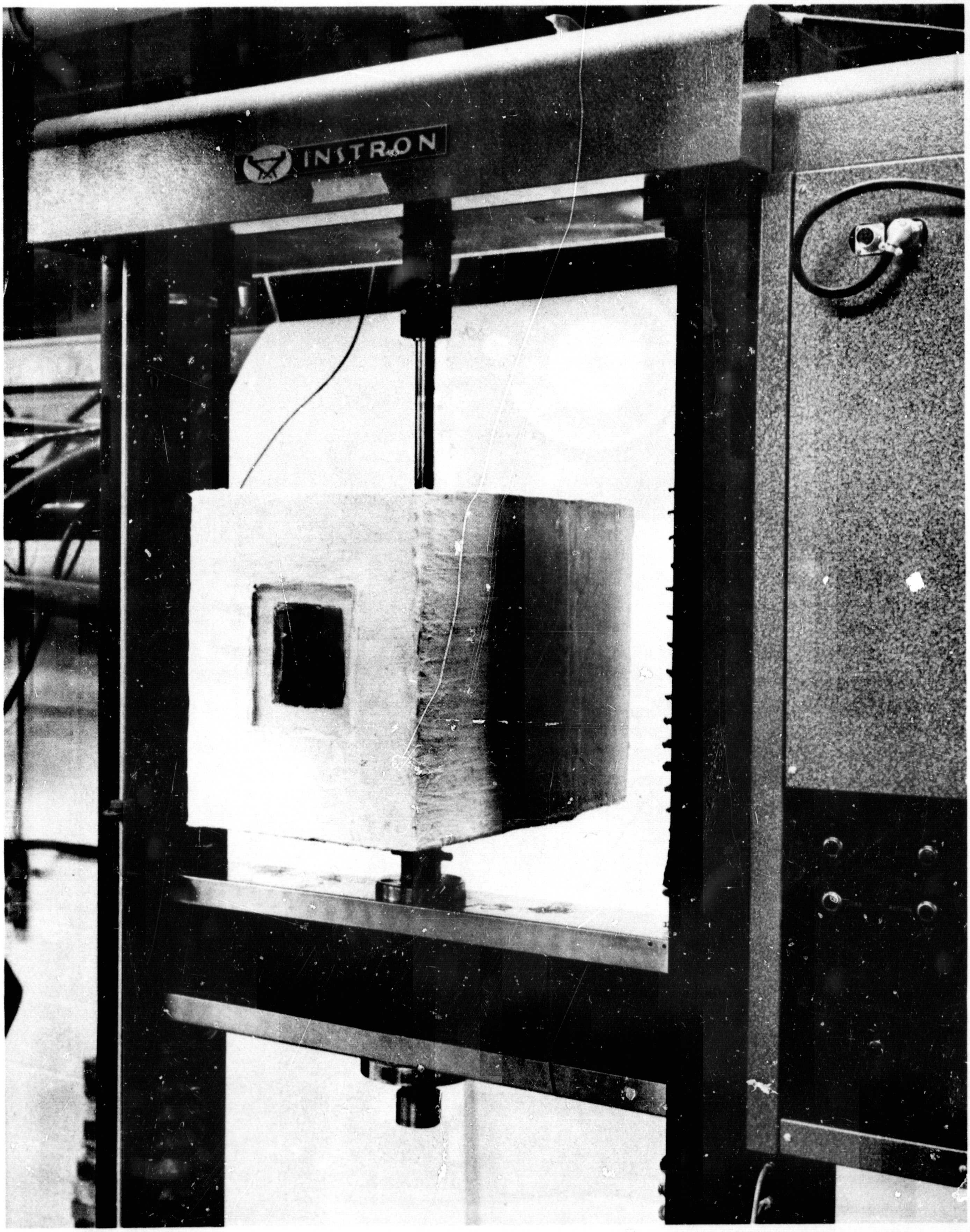


Figure 4-1 Instron Cryostat Mounted in Test Position

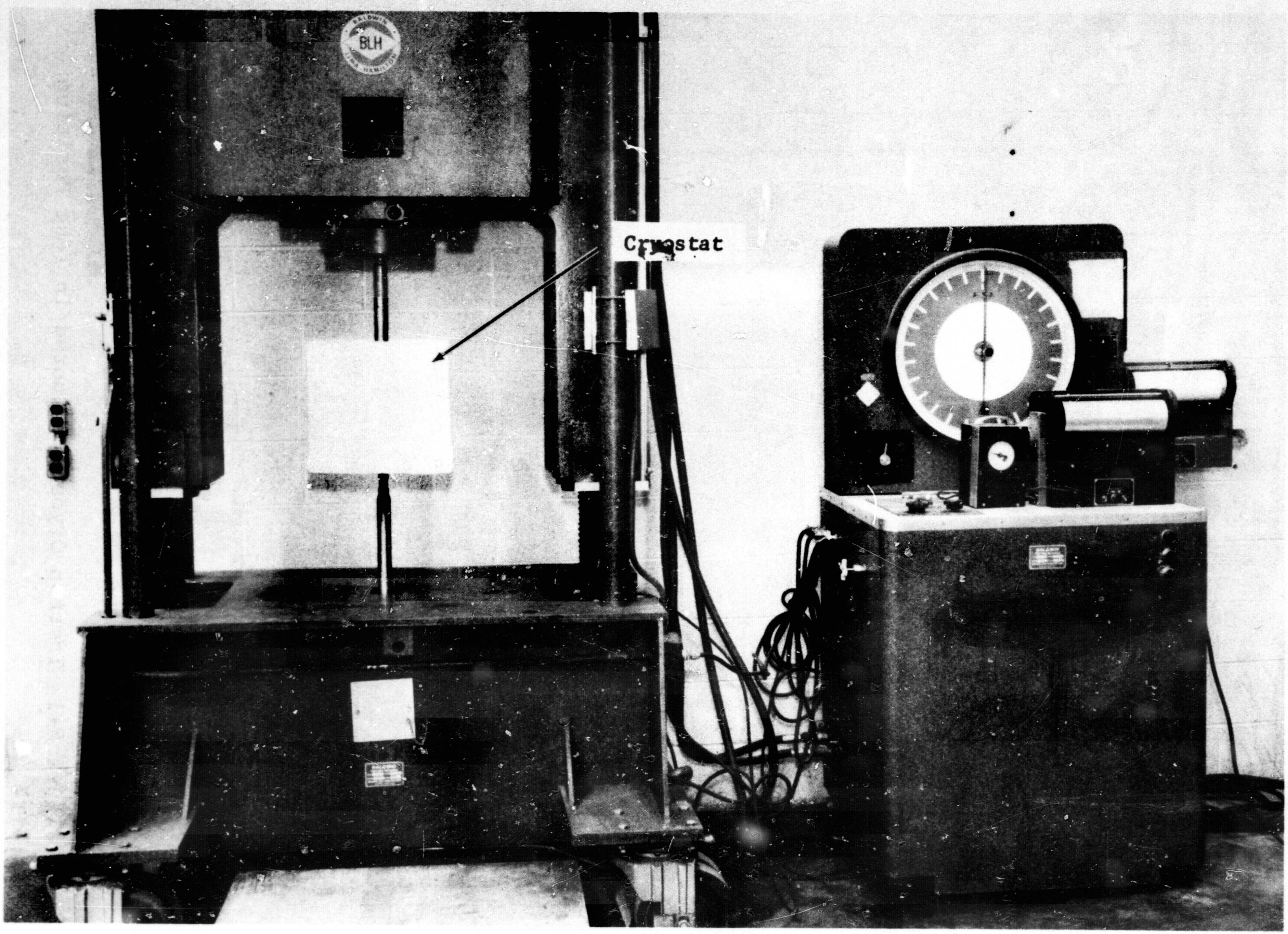


Figure 4-2 Baldwin Tester Used for Testing Titanium Fracture Toughness Specimens

In tensile tests performed above $540^{\circ}R$ (one material) specimen test temperature was maintained by use of a Norton Model 2285 furnace set up as shown in Figure 4-3. The temperature calibration procedures for elevated temperature tests and for the low temperature tests between 140° and $540^{\circ}R$ are described in Sections 4.2.2.1 and 4.2.2.2, respectively.

4.1.2 Displacement Gages for Use in Fracture Toughness Tests

The displacement gages used in fracture toughness tests were made according to ASTM Part 31, "Proposed Method of Test for Plane-Strain Fracture Toughness of Metallic Materials," dated 31 May 1970. Figure 4-4 is a drawing of a typical displacement gage mounted in a specimen, and Figure 4-5 is a photograph of a displacement gage mounted in a specimen. Figure 4-6 is a dimensional drawing of the beams and spacer block.

The cantilever beams were made of either alpha or beta titanium, depending upon the availability of the material.

Two types of foil strain gages were purchased from two separate manufacturers. Epoxy bonding material compatible with the respective gages was chosen to bond the strain gages to the beams. Strain gage type SA-06-125AC-350, manufactured by Micro-Measurements, Romulus, Michigan, was bonded onto the beams with

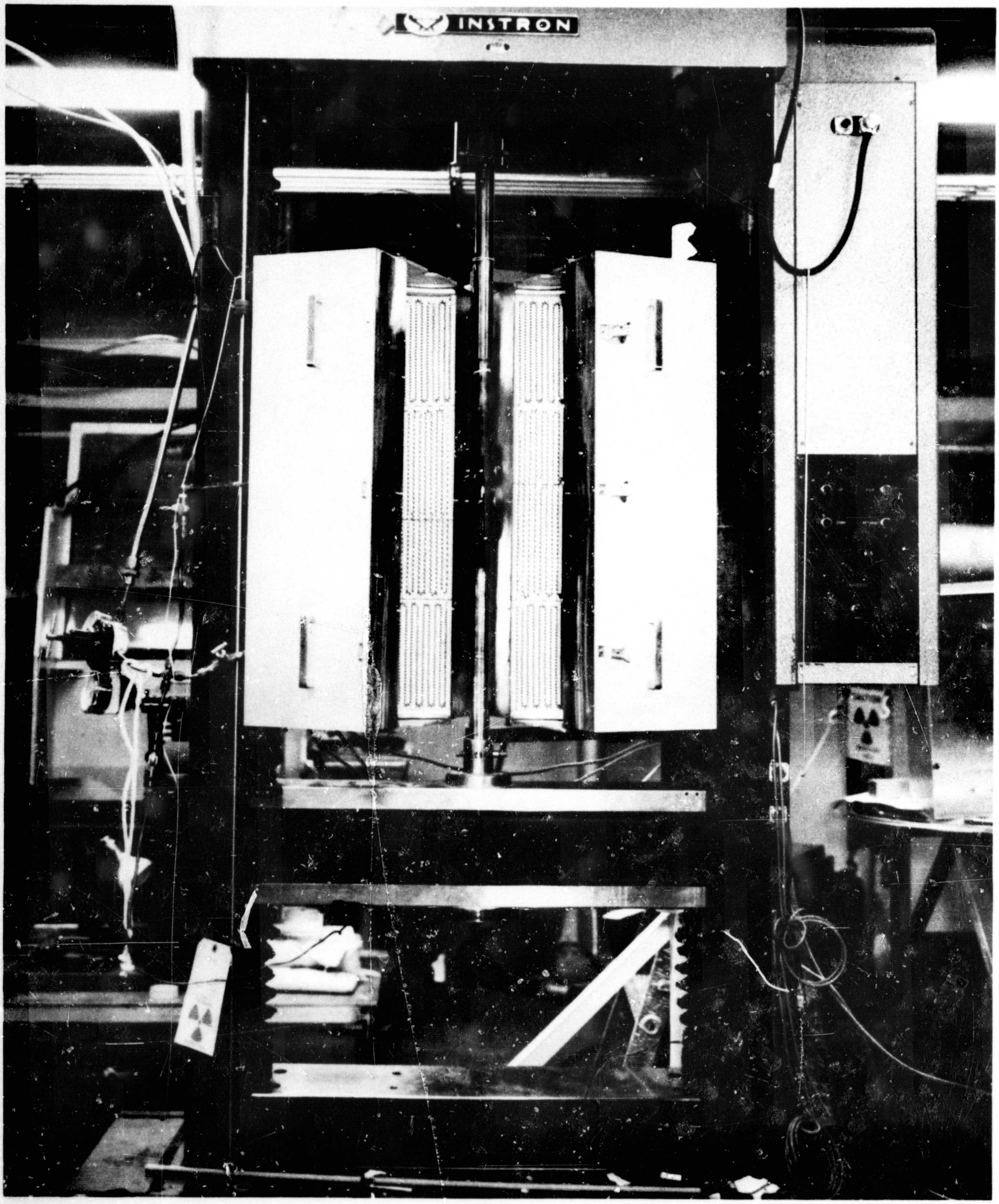


Figure 4-3 Norton Model 2285 Split Furnace Installed on Instron Model TT-D Tester

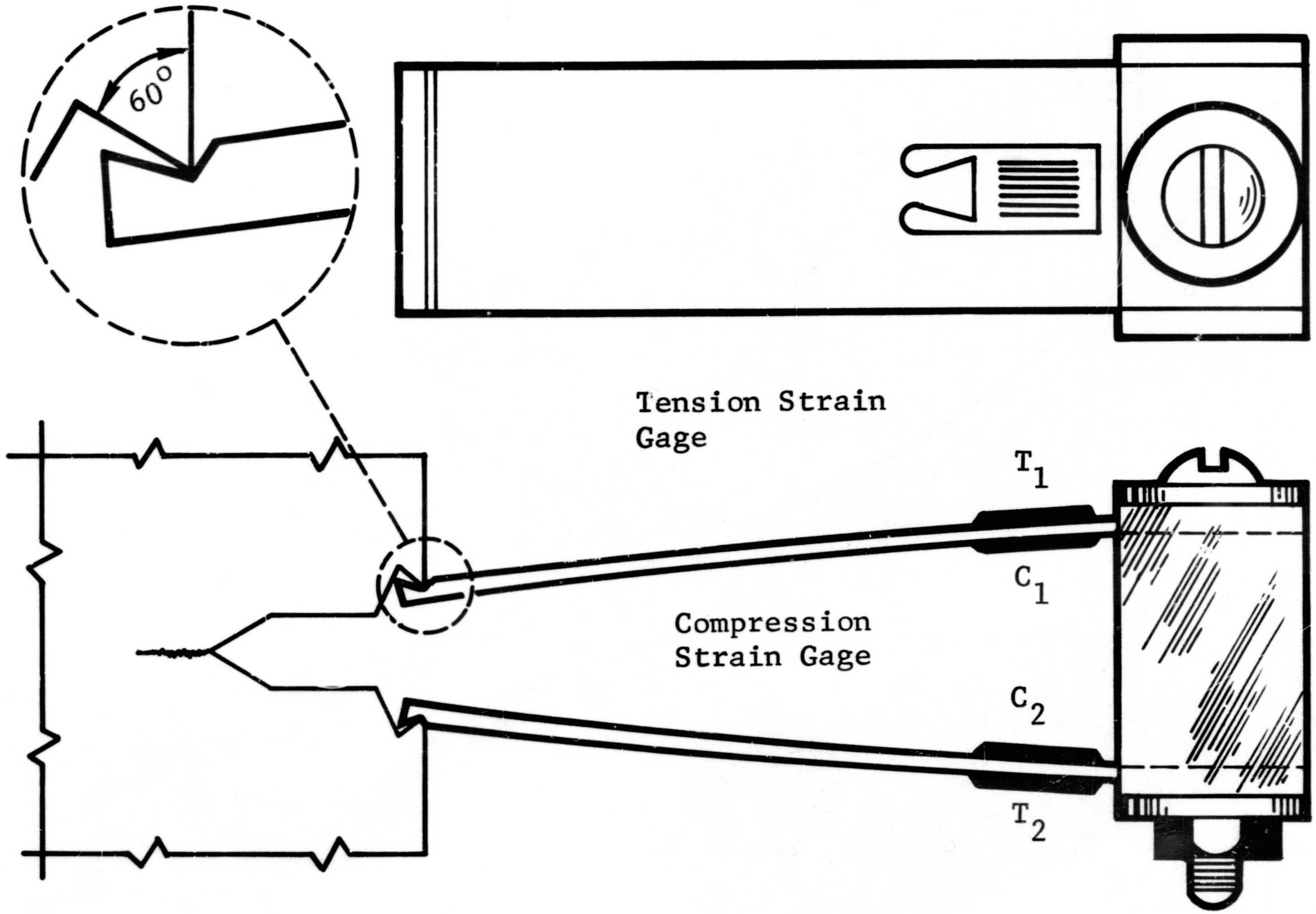


Figure 4-4 Typical Displacement Gage Mounted in a Specimen

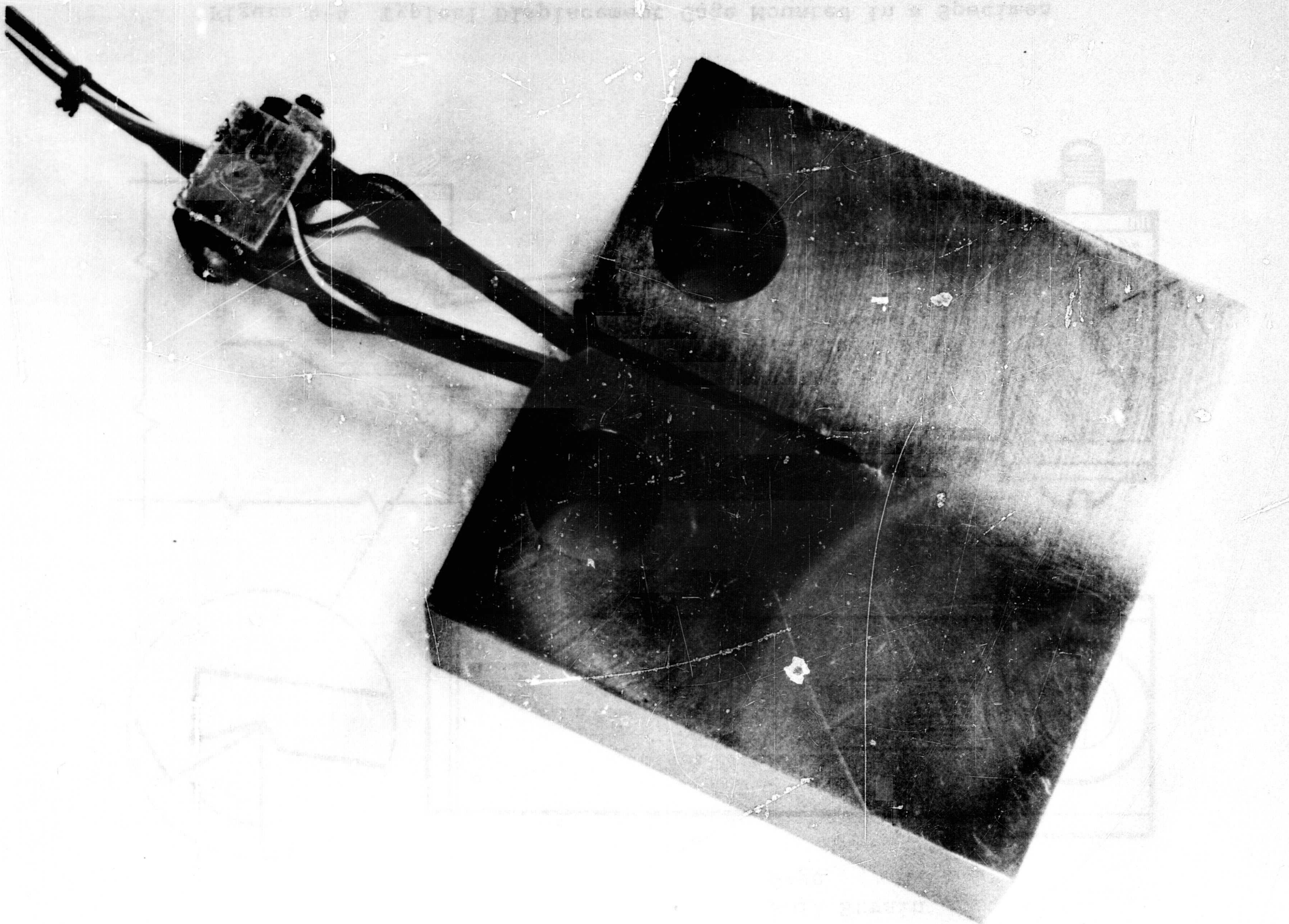
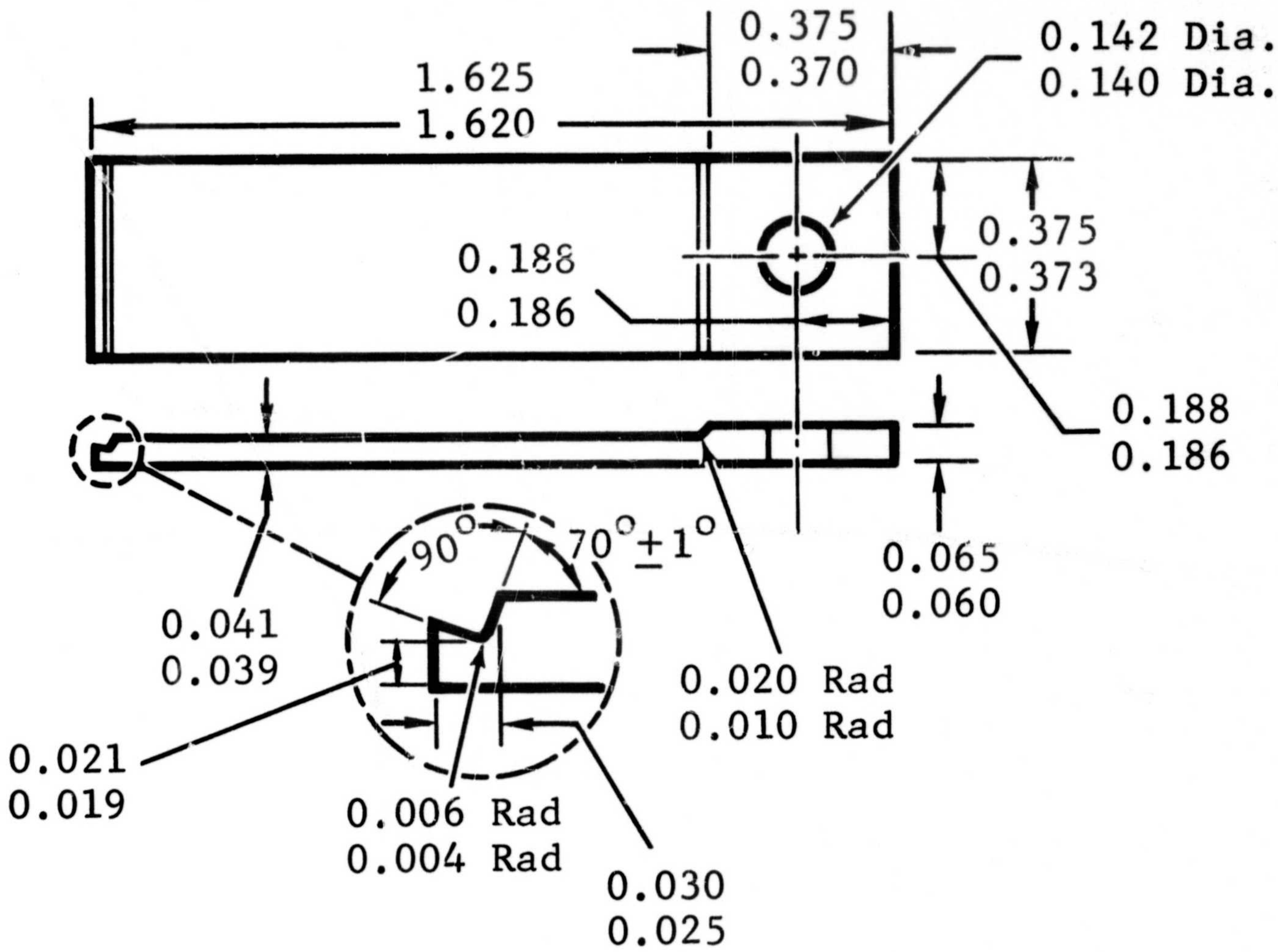
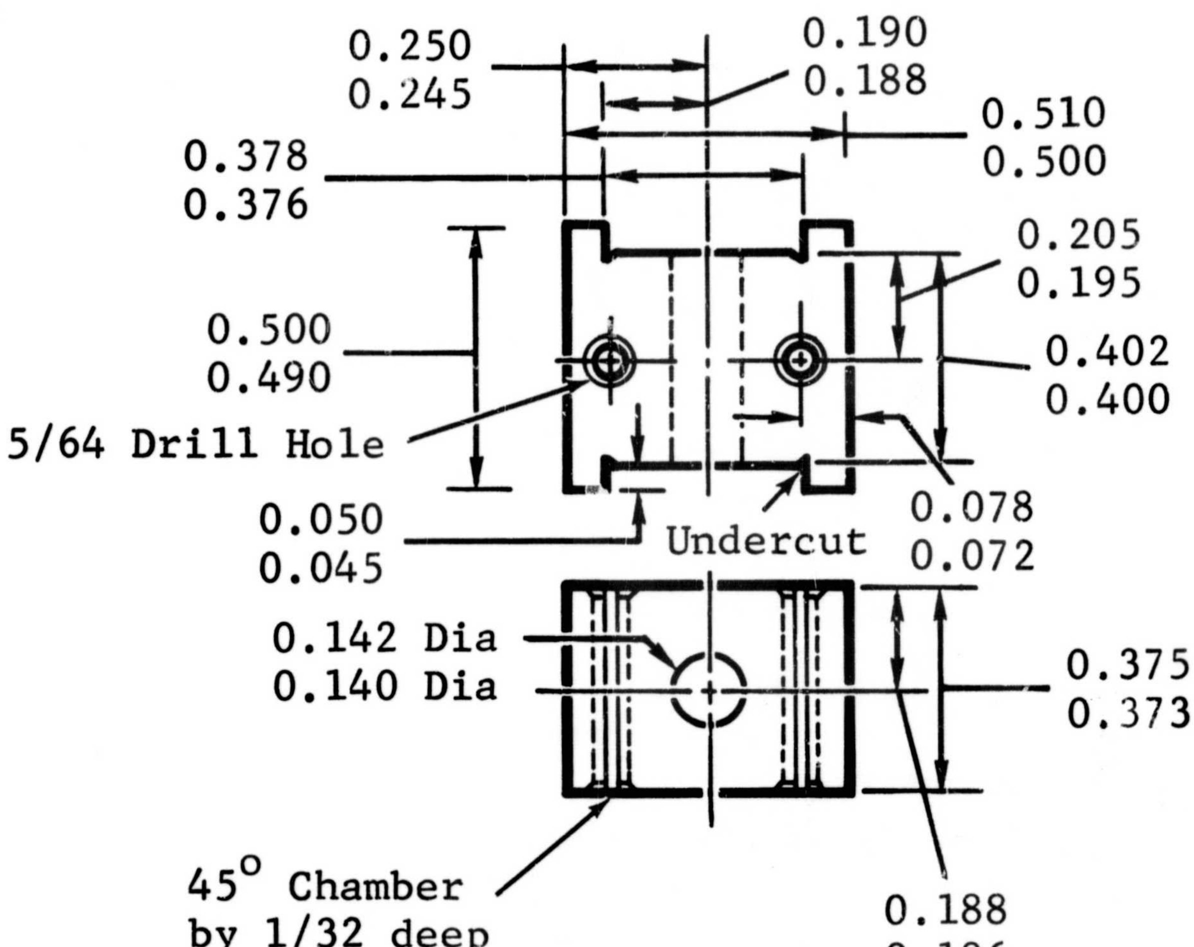


Figure 4-5 Fracture Toughness Specimen with Displacement Gage in Place



(a) dimensions of beams

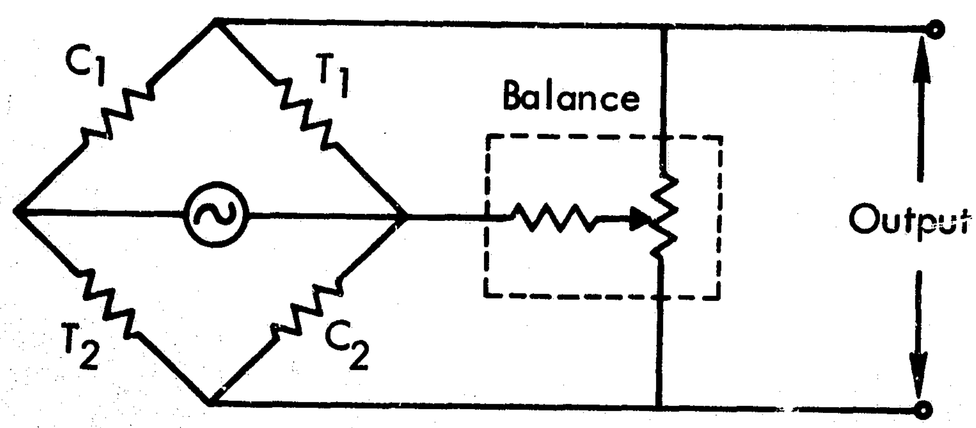


(b) dimensions of spacer block

Figure 4-6 Dimensional Drawing of Displacement Gage Beams and Spacer Block

M-Bond 600 epoxy. Strain gage type FSM-25-35S6, manufactured by BLH Electronics, Waltham, Mass., was bonded onto the beams with EPY 550 epoxy.

Two gages of the same type were bonded onto each of the two beams as close as possible to the beam spacer block. The four gages were connected as shown in the sketch below. The bridge circuit provides maximum displacement gage sensitivity and self temperature compensation.



Displacement Gage Bridge Circuit

4.2 Test Methods

4.2.1 Axiality Checks for the ANSC Tensile Specimens

In order to ascertain that the pull rods, the specimen grips, and the specimens within the grips were all aligned so as to provide axial loading of the test specimens, axiality checks were performed prior to initiating tensile tests. The checks were performed at room temperature on both Instron machines using a strain gage instrumented specimen provided by ANSC.

2

The axiality checks were performed in accordance with ANSC Preliminary Standard Procedure RE-1, "Procedure for Axiality Determination for Tensile Test Apparatus," dated July 1970. The procedure provides a method for assessment of the stability of the load train, the magnitudes and directions of the bending strains over the specimen length, and proportions of the bending strain due to test apparatus and test specimens.

The following are the general requirements of the procedure:

1. <u>Axiality Test Specimen (ATS)</u>

   a. The ATS shall be of the same configuration in the grip or holder area and the same length as the specimens used for data collection.

   b. The ATS shall be of a material and dimension sufficient to withstand the anticipated load required to yield the data collection specimens without yielding the ATS. The maximum anticipated load should correspond to approximately 60 to 70 percent of the ATS material yield strength.

2. <u>Load Train</u>

   a. Mark all load train components with a continuous vertical line. All components, except the ATS, must be kept in the same angular position throughout the test series.

   b. Record the relationship between the location of the load train vertical line and some permanent fixture of the test machine. An accuracy of $\pm 5^{\circ}$ is sufficient for this purpose.

   c. Record the relationship between the ATS and the test machine so that location of strain gages with respect to the test machine can be determined.

d. The condition of the load train for the axiality test shall be the same as for data collection.

3. Strain Gages

Foil gages of 120-ohm resistance shall be used. Size of the gage will be determined by the space available.

4. Collection of Axiality Data

Record strain gage readings in microinches per inch.

a. Take strain gage readings with the load train hanging freely.

b. Load the ATS to the required value and hold constant while recording the output from the strain gages.

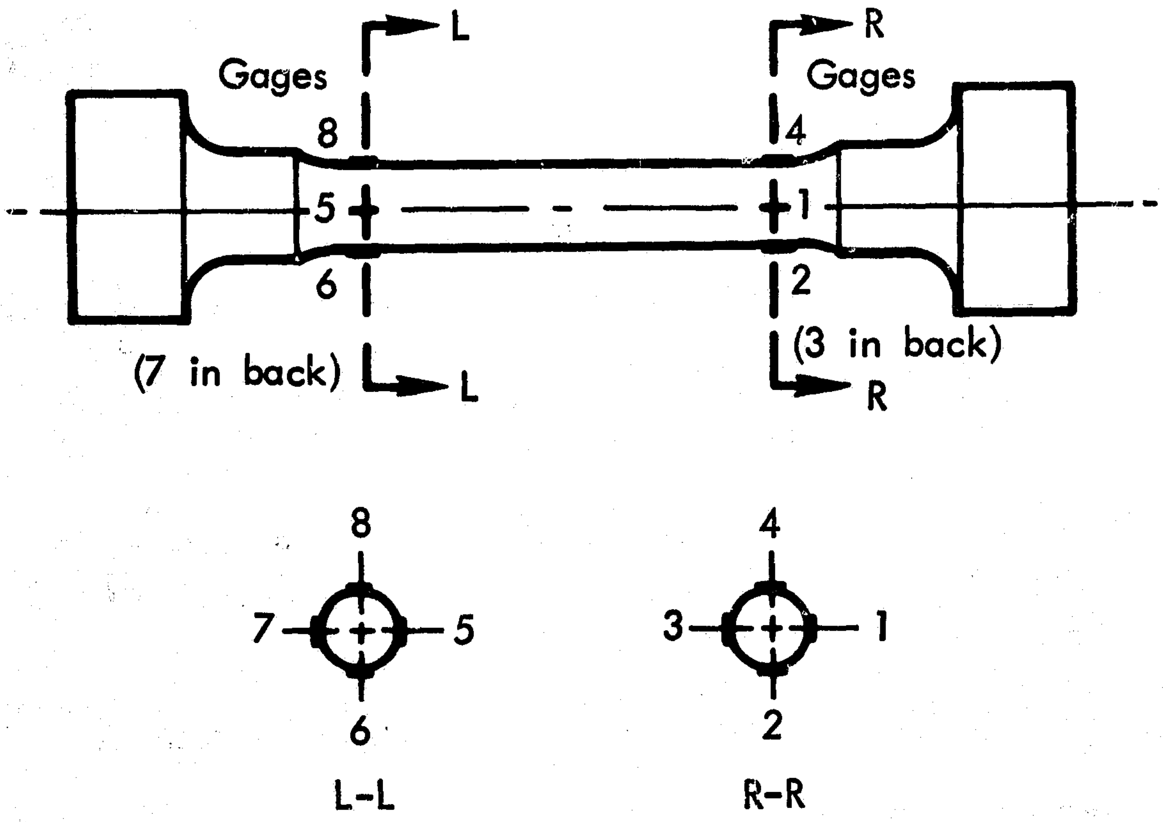
c. Release the load and read the gages again.

d. Rotate the ATS 180° and repeat the test. Do not rotate the load train or any portion thereof.

e. Return the specimen to its original position. Repeat the cycle of two loadings (specimen at 0° and 180°) so as to obtain five loadings in the first position (0°) alternating with five loadings in the second position (180°).

Axiality tests performed prior to testing all buttonhead specimens were accomplished with an Inconel 718 buttonhead specimen fabricated to AGC Drawing No. 1134298-1 with strain gage assemblies mounted according to AGC Drawing No. 1138347. The ATS was equipped with two sets of four strain gages each. One set of four gages was placed near each end of the gage section,

and the gages were spaced circumferentially (90° Apart) as indicated in the sketch below.



Sketch of Strain Gage Location for Round Axiality Test Specimen (ATS)

The results of axiality tests performed prior to testing the buttonhead specimens showed that the maximum bending strain due to the apparatus was 6.8%. ANSC has concluded that a tolerance of 9.2% maximum bending strain due to apparatus at the center of the specimen will provide acceptable axiality.

4.2.2 Temperature Calibration Procedures

4.2.2.1 Calibration Procedures for 740°R

In the test requiring specimens to be tested at a temperature of 740°R, the temperature of the specimen during testing

was controlled by monitoring and regulating the temperatures of the specimen grips. The calibration procedure was as follows:

1. Thermocouples were embedded in both the upper and lower grips.

2. A thermocouple was resistance welded or embedded in the center of the gage-length section of a specimen of the same configuration and material as that to be tested.

3. The thermocouple-instrumented specimen was then placed in the Instron grips and the furnace was closed.

4. Power was applied to the furnace by each of three temperature controllers. When the specimen-mounted thermocouple reached the desired test temperature, the control setting for each controller was adjusted to maintain the desired test temperature and to minimize temperature gradients between the specimen and grips.

5. With the specimen temperature stabilized, the setting for each temperature controller was noted.

6. During the tests, the temperature of each specimen was controlled by the three temperature controllers and monitored by the temperatures of the upper and lower grips.

The calibration procedure was repeated several times at each test temperature to ensure reproducible results.

4.2.2.2 Calibration of Cold GN_2 Fixture for Temperatures Between 140^o and 540^oR

Calibration of the double-walled GN_2 temperature control fixture for test temperatures of 276^o, 340^o, and 406^oR was

accomplished in much the same manner as for elevated temperature tests. The calibration procedure was as follows:

1. Thermocouples were embedded in both the upper and lower grips.

2. A thermocouple was resistance welded or embedded in the center of the gage-length section of a specimen of the same configuration and material as that to be tested.

3. The Instron cryostat was filled with LN_2.

4. The thermocouple-instrumented specimen was then placed in the Instron grips and the double-walled GN_2 fixture lowered into position to encase the grips and specimen.

5. The LN_2 was drained from the cryostat and flow of cold GN_2 through the double-walled fixture was initiated.

6. Flow of GN_2 was controlled manually until the temperature approached to within about 50^o of the desired temperature, at which time the system was switched to automatic control and brought to the test temperature. Once the temperature was reached, the set-point of the automatic control was adjusted to maintain the desired temperature. The automatic control actuated a solenoid valve which supplied GN_2 upon demand as sensed by one of the grip thermocouples.

4.2.3 Annealing of Specimens at 540^oR

The thermocouple-instrumented specimen was placed in LN_2 and allowed to cold soak for 30 minutes. Then it was removed from the LN_2 and placed in a water bath. The time/temperature profile of the instrumented specimen was monitored and the time required for it to reach 540^oR was noted; this was found to be approximately 1 minute. Therefore, specimens scheduled for annealing at 540^oR

were removed from LN_2 and submerged in water (1 gallon) until approximately 5 minutes before the annealing period was complete. They were then removed from the water, dipped in acetone, and dried. At the end of the specified annealing period plus 1 minute, the specimens were returned to LN_2 until tested.

4.2.4 Tensile Tests

For those specimens tested at 140°R, a cryostat, as described in Section 4.1.1, was installed in the tensile test machine as shown in Figure 4-1. The specimen to be tested was transferred from the handling dewar to the cryostat using a small dipper so that it remained submerged in LN_2 at all times. The specimen was then loaded into the grips and tested to fracture in accordance with the applicable test specifications.

For tensile tests at 340° the double-walled fixture described in Section 4.1.1 was used in conjunction with the LN_2 cryostat used in testing at 140°R. The fixture was installed in the tensile test machine so that it enclosed the specimen grips. With the cryostat filled with LN_2, the specimen was loaded into the grips and cold GN_2 flow was initiated to the annealing fixture. The LN_2 was then drained from the cryostat. The GN_2 flow rate and temperature was varied as required to warm the specimen to the desired temperature, as indicated by the grip thermocouples,

and to maintain it at temperature until the specimen had been tested to fracture.

For tests performed at 740°R, the Norton Model 2285 furnace was installed on the Instron Model TT-D tester as shown in Figure 4-3. The furnace was preheated to the desired temperature and control settings established at each test temperature using the procedures outlined in Section 4.2.2. Each specimen to be tested was removed from the LN_2 storage dewar and placed in a water bath (1 gallon) for approximately 1 minute. Then it was dipped in acetone and dried. The specimen was then placed in the Instron grips, heated to the desired test temperature, and (after a 5-minute soak period at temperature) pulled to fracture.

4.2.5 Fracture Toughness Tests

All of the fracture toughness specimens were tested in accordance with the applicable specifications. The displacement gage, described in Section 4.1.2 (Fig. 4-7), was used on all of the materials tested as fracture toughness specimens with the exception of the small ZrC specimens and the titanium sheet specimens.

Tests were performed at 140°R by use of the cryostat installed in the Instron. Specimens were transferred from the storage dewar to the test cryostat under LN_2. The displacement

gage was installed in the test specimen opening between the two gage points, allowed to stabilize at LN_2 temperature, and adjusted by the procedures described below.

For fracture toughness tests at temperatures between 140° and 540°R, the same fixtures and procedures as described for the tensile tests were used. Specimens to be tested at 540°R were removed from the LN_2 storage dewar and placed in a water bath for approximately 1 minute. It was then dipped in acetone and dried. Installation and use of the displacement gage was the same regardless of the test temperature.

The criteria used for evaluating the displacement gages conformed to that stated in ASTM Part 31, "Proposed Method of Test for Plane-Strain Fracture Toughness of Metallic Materials," dated 31 May 1970. Each displacement gage was tested over a range adequate for measuring the relative displacement of two gage points of a specimen under test. At zero displacement the distance between the gage points for the specimens tested was 0.20 in. and at maximum displacement, just before crack extension, the distance between the gage points was less than 0.25 in. Hence, the displacement gages were tested over a displacement range from 0.20 in. to 0.25 in.

The equipment used for evaluating the displacement gages consisted of a Boeckeler Micrometer, a strain gage switching and balancing unit, a strain indicator, a dewar to contain LN_2, and miscellaneous hardware.

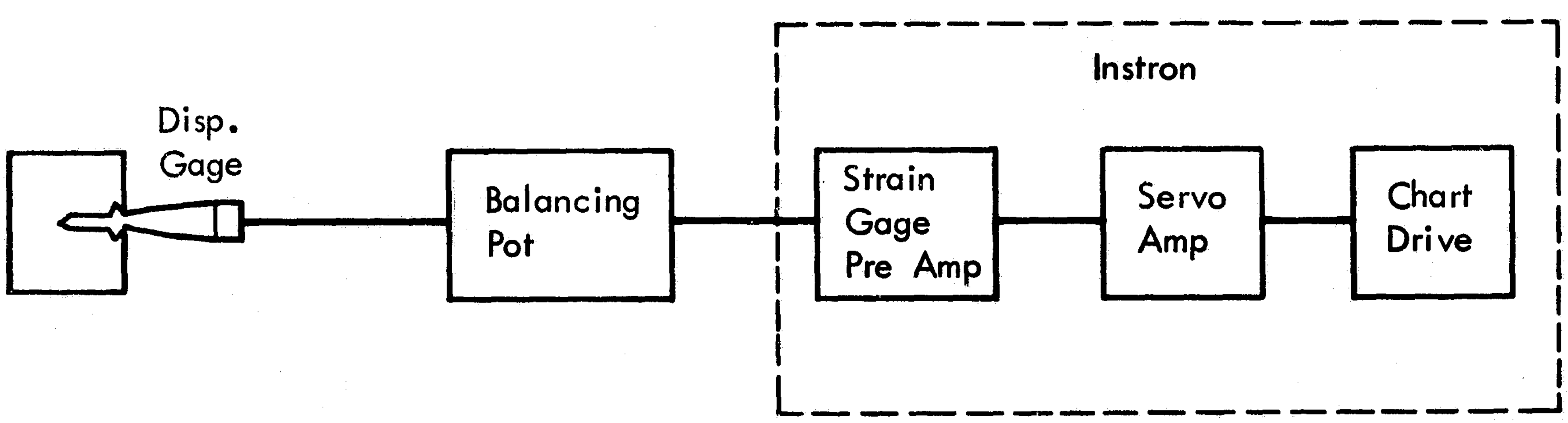
The Boeckeler Micrometer that was used for displacement interval settings is a precision instrument manufactured by Arizona Tool and Die Co., Tucson, Arizona. The instrument can be read to 0.00002 in. Special jaws were made for the micrometer with knife edges comparable to the gage points of a specimen. The knife edges allowed proper engagement of the displacement gage.

A Model 225 Switching and Balancing Unit and a Model 120C Strain Indicator, both manufactured by BLH Electronics, Inc., were used for balancing and indicating displacement gage output. The strain indicator has a readability of 1 microinch/inch.

A minimum of three sets of data were recorded at test temperatures of 140°, 273°, 406°, and 540°R. Temperature stabilization for 30 min was allowed (as required by the test specification) at each test temperature before readings were taken. To obtain accurate data it was necessary to maintain the gage and a portion of the micrometer at the test temperature. Readings were obtained for ten displacement intervals of 0.005 in. between 0.20 in. and 0.25 in. After each set of data, the gage was removed and reinstalled in the micrometer before the next set of data was taken.

The data were analyzed to detect deviations from linearity over the displacement range. The required linearity corresponded to a maximum deviation of 0.001 in. of the individual displacement readings from a least-squares best-fit straight line through the data. Displacement gages which did not conform to the linearity criterion were rejected.

In setting up for the fracture toughness testing, the displacement gage was connected to the Instron chart drive system by means of an external balance potentiometer and the Instron strain-gage preamplifier as shown in the sketch below.



Sketch of Displacement Gage Connected with Instron Chart Drive System

Calibration of the displacement gage and Instron system was obtained with the displacement gage set in the micrometer initially at 0.20 in. opening and the gage and a portion of the micrometer at the test temperature. After 30 min for temperature stabilization, the strain-gage preamplifier was nulled by alternately adjusting the external balance potentiometer and

strain-gage preamplifier balance control. Upon completion of null, the displacement gage was opened to force chart travel. The gain of the preamplifier was adjusted to give the desired chart travel. Normally, this was 1 in. for 0.004 in. of displacement gage opening. Linearity of the system was satisfactory over the operating range.

In testing the fracture toughness specimens, the displacement gage was placed in the specimen opening between the two gage points, allowed to stabilize at the test temperature, and then adjusted to null by the method described previously. The specimens were pulled at a constant loading rate, with the exception of CuB, with the load being recorded on the x axis of the Instron chart. Chart travel in the y direction was proportional to the displacement change between the two gage points. A linear record of displacement vs load was obtained up to the point of crack extension.

4.2.6 Tear Test

The tear test was performed by use of the Model TT-D Instron machine operated in the same manner as for tensile tests. Tests at 140° and $340^{\circ}R$ were by the same techniques as described in Section 4.2.4. A load/deformation curve plotted on the Instron recorder with the machine operating at a constant crosshead speed provided the required data.

4.2.7 Flexure Tests

Flexure tests were performed on two materials by the procedure described in ASTM Procedure D790 (Ref. 1). The Feuralon plastic was tested with a setup similar to that illustrated in Sketch (a) of D790. Three-eighths-inch-diameter rods were used for support and loading; the span was 4.0 in. The Model TT-D Instron operating at a constant crosshead speed was used to apply the load.

A test fixture for the small ZrC flexure specimens was not available so the procedure was somewhat different in that the supports were flat surfaces with a one-inch span. The load was applied with a 3/8-in.-diam rod by use of the Model TT-D Instron operating at a constant crosshead speed.

4.2.8 Test of Springs

The springs were loaded in compression by use of the Model TT-C Instron. Load was applied at a constant crosshead speed up to the maximum specified deflection. The Belleville springs were tested in a fixture which mechanically limited the compression to 0.081 in. Load/deflection charts recorded on the Instron recorder provided the required data.

4.2.9 Sliding Wear Test

The actuator lubricant was tested by use of the Hohman A-6 sliding wear tester (Fig. 4-7). A bearing load of 110 lb per

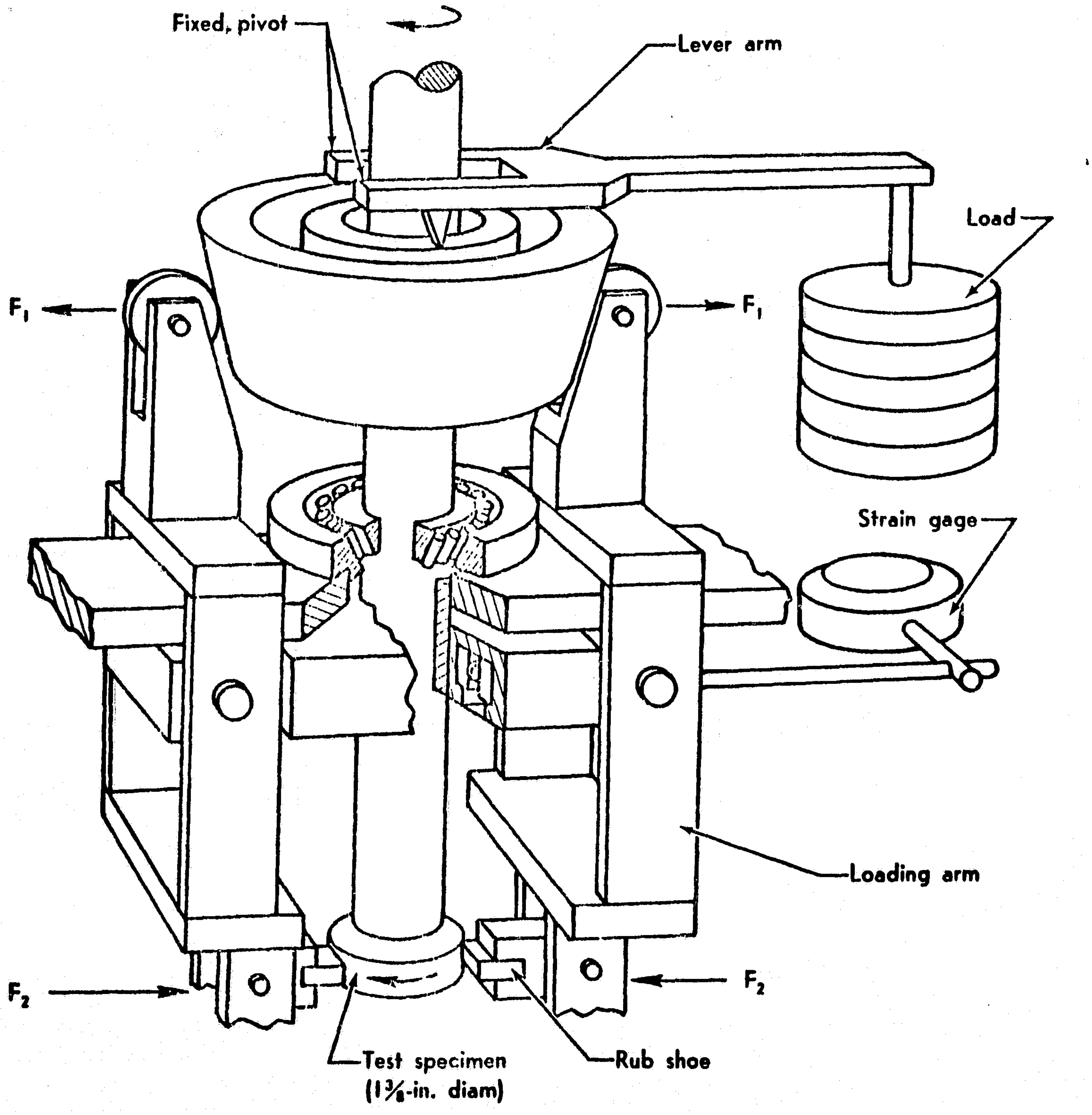


Figure 4-7 Diagrammatic Sketch of Hohman A-6 Wear Tester

rub shoe was applied to the test cup having a speed of 128 sliding feet per minute. The test was terminated when the friction coefficient reached 0.4.

4.2.10 Bench Measurements

Bench measurement data used for calculating percent elongation and percent reduction of area were measured with a Scherrer-Tumico Model P-1500 optical comparator. Special fixtures were designed to align the broken specimens and fit them together, thus facilitating determination of specimen length at fracture and cross-sectional area. These measurements were compared with preirradiation data which were also obtained with the optical comparator.

Bench measurement data required for determination of fracture toughness characteristics were also obtained with the Scherrer-Tumico optical comparator. The dimensions of the precrack profile were measured after fracture; all other measurements were obtained prior to irradiation.

4.2.11 Photography

Photographs were taken showing the fracture surface of selected broken specimens. These photographs are not contained in this report but were submitted directly to LASL.

V. PRESENTATION OF DATA

5.1 Tensile Data

The tensile data in Tables 5-1 through 5-16 are presented in the following order:

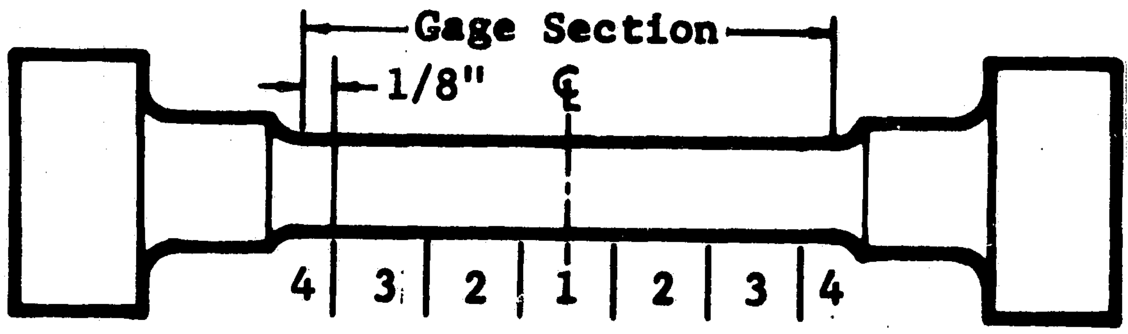
M-9-1 Titanium 6Al 4V (sheet)
M-9-2 Titanium 6Al 4V (welded sheet)
M-16-1 18 Ni Maraging Steel
M-21-1 Aluminum 7075-T73
M-31-1 AISI 9310 Steel
M-38-1 ARMCO 22-13-5 Steel
M-38-4 ARMCO 22-13-5 Steel
M-40-1 Titanium 5Al 2.5Sn (unnotched and notched)
M-40-1 Hastelloy X (unnotched and notched)
RTS-60 Aluminum 6061-T61 (unnotched and notched)
RTS-62 Aluminum 5086-H-34 (unwelded and welded sheet)

The following general information and property data are presented in the data tables for the unnotched specimens:

1. Designation of the material
2. Drawing number
3. Specimen number
4. Test condition (control or irradiated)
5. Instron crosshead speed
6. Irradiation and test temperatures
7. Anneal time and temperature (if any)
8. Yield stress at 0.2% offset
9. Maximum stress
10. Fracture stress
11. Percent elongation from both Instron chart and bench measurements

12. Percent area reduction from bench measurements

13. Fracture location specified as 1, 2, 3, or 4 corresponding to the sections indicated in the sketch. Sections 1, 2, and 3 were of an equal length that depended upon the elongation. T or O indicates that the break was, roughly, transverse or oblique, respectively.



Similar information is given for the notched specimens except that the tensile data consists of:

1. Average notch diameter
2. Area at notch
3. Fracture load
4. Fracture stress

Averages, standard deviations, and percent standard deviations have been computed for each group of specimens irradiated and tested under the same conditions. Table S-1 in the Summary gives the percent difference between data for the irradiated and control specimens and indicates if the difference is statistically significant at the 95% confidence level.

Table 5-1

TENSILE DATA FOR TITANIUM 6Al 4V SHEET IRRADIATED AT 140°R AND TESTED AT 140° AND 540°R

Crosshead Speed = 0.075 in./min (Specification M-9-1)

Specimen Number	Test Temp (°R)	Tensile Stress: 0.2% Offset (ksi)	Tensile Stress: Max (ksi)	Tensile Stress: Fract (ksi)	% Elongation: Bench	% Elongation: Chart: To Max Stress	% Elongation: Chart: To Fract	% Area Reduct (Bench)	Fracture Location	Radiation Exposure: Neutron Fluence (n/cm²): E > 1 MeV	Radiation Exposure: Neutron Fluence (n/cm²): E < 0.48 eV
22	140	200.1	215.4	215.4	19.2	18.7	18.7	11.1		Control	
32	140	202.1	214.9	214.9	19.3	17.3	17.3	9.9		Control	
43	140	197.3	216.0	215.1	23.2	18.0	24.3	15.8		Control	
AVG		199.8	215.4	215.1	20.6	18.0	20.1	12.27			
STD DEV		2.41	0.55	0.25	2.28	0.70	3.70	3.12			
% STD DEV		1.21	0.26	0.12	11.1	3.89	18.43	25.42			
20	140	204.3	215.6	215.3	23.0	18.3	23.1	10.8		3.05 (16)	1.8 (15)
28	140	203.8	215.5	215.3	12.3	8.5	12.1	11.3		3.05 (16)	1.8 (15)
34	140	204.0	216.7	216.5	20.9	16.4	21.2	13.0		3.05 (16)	1.8 (15)
AVG		204.0	215.9	215.7	18.7	14.4	18.8	11.7			
STD DEV		0.25	0.67	0.69	5.67	5.20	5.88	1.15			
% STD DEV		0.12	0.31	0.32	30.26	36.09	31.27	9.86			
16	140	213.2	223.1	219.4	12.2	4.6	13.8	15.5		4.70 (17)	1.8 (16)
21	140	207.5	224.6	222.1	16.8	6.2	17.9	10.4		4.70 (17)	1.8 (16)
33	140	207.4	224.5	219.6	17.2	4.1	15.8	11.3		4.70 (17)	1.8 (16)
AVG		209.4	224.1	220.4	15.4	5.0	15.8	12.4			
STD DEV		3.32	0.84	1.50	2.78	1.10	2.05	2.72			
% STD DEV		1.59	0.37	0.68	18.04	22.09	12.95	21.95			
31	540	124.4	134.2	124.4	17.5	6.9	17.2	12.3		4.70 (17)	1.8 (16)
44	540	125.1	134.8	125.6	17.0	7.2	16.7	17.0		4.70 (17)	1.8 (16)
AVG		124.8	134.5	125.0	17.2	7.0	17.0	14.6			
STD DEV		0.5	0.4	0.8	0.4	0.2	0.4	3.3			
% STD DEV		0.4	0.3	0.7	2.0	3.0	2.1	22.7			
19*	140	196.1	218.2	218.0	12.2	5.1	11.0	6.0		4.70 (17)	1.8 (16)
24*	140	201.9	219.1	218.8	16.0	6.0	14.9	12.3		4.70 (17)	1.8 (16)
37*	140	201.8	218.9	218.6	22.0	5.4	18.4	9.9		4.70 (17)	1.8 (16)
AVG		199.9	218.7	218.5	16.7	5.5	14.8	9.4			
STD DEV		3.32	0.47	0.42	4.94	0.46	3.70	3.18			
% STD DEV		1.66	0.22	0.19	29.53	8.33	25.07	33.83			

* Annealed for 100 min at 540°R

ANSC Dwg. No. 1138194-1909. Data to be used for material evaluation only. Do not use for design.

Table 5-2

TENSILE DATA FOR TITANIUM 6Al 4V SHEET IRRADIATED IN WATER AT 550°R AND TESTED AT 140° and 540°R
(Specification M-9-1)

Crosshead Speed = 0.075 in./min

Specimen Number	Test Temp (°R)	Tensile Stress			% Elongation			% Area Reduct (Bench)	Fracture Location	Radiation Exposure	
					Bench	Chart				Neutron Fluence (n/cm²)	
		0.2% Offset (ksi)	Max (ksi)	Fract (ksi)		To Max Stress	To Fract			E > 1 MeV	E < 0.48 eV
25	540	120.1	131.2	122.8	18.2	9.5	18.1	13.4		Control	
29	540	122.1	133.1	124.1	19.5	9.5	18.5	13.4		Control	
35	540	122.7	134.7	124.9	19.7	8.7	18.9	15.7		Control	
AVG		121.6	133.0	123.9	19.1	9.2	18.5	14.2			
STD DEV		1.36	1.75	1.06	0.81	0.46	0.40	1.33			
% STD DEV		1.12	1.32	0.85	4.25	5.00	2.16	9.37			
23	140	203.3	215.5	214.3	19.0	14.1	18.7	15.9		1.52 (17)	6.6 (17)
27	140	204.3	214.9	214.2	19.9	13.9	20.0	15.1		1.52 (17)	6.6 (17)
39	140	203.5	216.2	215.2	23.4	17.3	23.1	16.2		1.52 (17)	6.6 (17)
AVG		203.7	215.5	214.6	20.8	15.1	20.6	15.7			
STD DEV		0.53	0.65	0.55	2.32	1.91	2.26	0.57			
% STD DEV		0.26	0.30	0.25	11.19	12.63	10.97	3.61			
17	540	122.6	132.9	125.5	17.8	8.0	17.4	13.7		1.52 (17)	6.6 (17)
41	540	121.0	132.0	122.7	19.9	8.3	17.9	16.7		1.52 (17)	6.6 (17)
42	540	122.2	133.7	125.9	18.6	9.3	18.1	12.8		1.52 (17)	6.6 (17)
AVG		121.9	132.9	124.7	18.8	8.5	17.8	14.4			
STD DEV		0.83	0.85	1.74	1.06	0.68	0.36	2.04			
% STD DEV		0.68	0.64	1.40	5.65	7.98	2.03	14.18			
26	140	202.9	219.4	217.9	18.4	5.0	18.8	14.5		1.20 (18)	7.8 (18)
30	140	208.4	220.6	218.2	22.4	4.9	21.8	16.0		1.20 (18)	7.8 (18)
36	140	204.7	220.7	218.3	21.9	4.8	20.5	14.0		1.20 (18)	7.8 (18)
AVG		205.3	220.2	218.1	20.9	4.9	20.4	14.8			
STD DEV		2.80	0.72	0.21	2.18	0.10	1.50	1.04			
% STD DEV		1.37	0.33	0.09	10.43	2.04	7.39	7.02			
18	540	127.1	136.1	126.1	19.2	7.3	18.8	15.1		1.20 (18)	7.8 (18)
38	540	126.6	135.0	124.2	16.4	6.6	16.2	14.3		1.20 (18)	7.8 (18)
40	540	125.8	134.6	129.7	13.6	6.2	11.8	11.7		1.20 (18)	7.8 (18)
AVG		126.5	135.2	126.7	16.4	6.7	15.6	13.7			
STD		0.66	0.78	2.79	2.80	0.56	3.54	1.78			
% STD DEV		0.52	0.57	2.20	17.07	8.31	22.68	12.97			

ANSC Dwg. No. 1138194-1909. Data to be used for material evaluation only. Do not use for design.

Table 5-3

TENSILE DATA FOR TITANIUM 6Al 4V WELDED SHEET IRRADIATED AND TESTED AT 140^{o}R
(Specification M-9-2)

Crosshead Speed = 0.050 in./min

Specimen Number	Test Temp (^{o}R)	Tensile Stress: 0.2% Offset (ksi)	Tensile Stress: Max (ksi)	Tensile Stress: Fract (ksi)	% Elongation: Bench	% Elongation: Chart: To Max Stress	% Elongation: Chart: To Fract	% Area Reduct (Bench)	Fracture Location	Radiation Exposure: Neutron Fluence (n/cm^2): E > 1 MeV	Radiation Exposure: Neutron Fluence (n/cm^2): E < 0.48 eV
52		211.5	217.3	216.7	15.2	12.2	15.2	17.6		Control	
54		211.2	217.7	216.2	14.0	11.8	14.3	12.7		Control	
56		213.7	218.6	216.6	16.9	11.2	16.2	7.2		Control	
59		211.7	218.5	218.2	14.1	12.6	14.7	9.7		Control	
60		212.1	218.5	217.9	14.6	5.6	14.3	11.5		Control	
AVG		212.0	218.1	217.1	15.0	10.7	14.9	11.7			
STD DEV		0.98	0.58	0.88	1.18	2.89	0.80	3.88			
% STD DEV		0.46	0.27	0.40	7.92	27.03	5.32	33.01			
47		214.1	219.4	217.6	15.9	11.4	15.7	13.4		3.05 (16)	1.80 (15)
49		212.9	218.4	217.6	12.2	4.6	12.2	14.4		3.05 (16)	1.80 (15)
50		214.6	219.1	218.5	14.0	9.9	13.7	16.2		3.05 (16)	1.80 (15)
51		209.3	218.2	216.7	12.6	8.8	13.1	15.9		3.05 (16)	1.80 (15)
53		212.6	218.7	218.4	13.1	10.1	13.1	17.7		3.05 (16)	1.80 (15)
AVG		212.7	218.8	217.8	13.6	9.0	13.6	15.5			
STD DEV		2.07	0.49	0.73	1.47	2.61	1.31	1.67			
% STD DEV		0.97	0.22	0.33	10.85	29.09	9.67	10.74			
46		216.5	225.4	218.0	15.2	3.0	14.6	1.8		4.7 (17)	1.80 (16)
48		219.8	225.9	223.1	10.4	2.3	9.4	6.8		4.7 (17)	1.80 (16)
55		218.4	223.9	222.4	9.8	2.6	7.9	5.5		4.7 (17)	1.80 (16)
57		215.7	223.4	221.0	8.1	2.7	7.4	3.8		4.7 (17)	1.80 (16)
58		215.9	224.5	222.2	8.2	2.8	7.9	7.5		4.7 (17)	1.80 (16)
AVG		217.3	224.6	221.3	10.3	2.7	9.4	5.1			
STD DEV		1.78	1.03	2.01	2.89	0.26	2.98	2.31			
% STD DEV		0.82	0.46	0.91	27.99	9.66	31.57	45.52			

ANSC Dwg. No. 1138194-2709. Data to be used for material evaluation only. Do not use for design.

Table 5-4

TENSILE DATA FOR 18 NI MARAGING STEEL FORGING IRRADIATED AND TESTED AT 140°R
(Specification M-16-1)

Crosshead Speed = 0.050 in./min

Specimen Number	Test Temp (°R)	Tensile Stress 0.2% Offset (ksi)	Tensile Stress Max (ksi)	Tensile Stress Fract (ksi)	% Elongation Bench	% Elongation Chart To Max Stress	% Elongation Chart To Fract	% Area Reduct (Bench)	Fracture Location	Radiation Exposure Neutron Fluence (n/cm²) E >1 MeV	Radiation Exposure Neutron Fluence (n/cm²) E <0.48 eV
Lot 1											
169		321.3	333.3	242.2	5.9	1.0	6.3	45.2	1/T	Control	
173		325.1	332.8	242.5	6.2	1.0	6.0	40.7	3/T	Control	
AVG		323.2	333.0	242.3	6.0	1.0	6.1	42.9			
STD DEV		2.69	0.35	0.21	0.21	0.0	0.21	3.18			
% STD DEV		0.83	0.11	0.09	3.51	0.0	3.45	7.41			
168		320.5	330.1	215.3	7.0	1.0	7.4	52.7	2/T	8.4 (16)	4.5 (15)
172		325.8	336.9	245.5	7.1	1.1	6.5	47.8	3/T	9.0 (16)	4.5 (15)
AVG		323.1	333.5	230.4	7.0	1.0	6.9	50.2			
STD DEV		3.75	4.81	21.35	0.07	0.07	0.64	3.46			
% STD DEV		1.16	1.44	9.27	1.00	6.73	9.16	6.89			
170		327.4	338.9	239.7	7.4	1.2	6.9	42.9	3/T	1.40 (18)	4.5 (16)
171		331.4	342.0	236.2	7.0	1.1	6.8	49.6	2/T	1.66 (18)	4.5 (16)
AVG		329.4	340.0	238.0	7.2	1.1	6.8	46.2			
STD DEV		2.8	2.2	2.5	0.28	0.07	0.07	4.74			
% STD DEV		0.9	0.6	1.0	3.93	6.15	1.03	10.24			
Lot 2											
177		318.8	326.4	229.4	6.1	0.8	6.1	44.5	3/T	Control	
178		319.3	326.5	223.7	7.0	1.0	7.1	49.4	3/T	Control	
AVG		319.0	326.4	226.5	6.5	0.9	6.6	46.9			
STD DEV		0.35	0.07	4.03	0.64	0.14	0.71	3.46			
% STD DEV		0.11	0.02	1.78	9.72	15.71	10.71	7.38			
176		314.1	326.7	231.3	6.1	1.0	6.5	47.2	3/T	7.5 (16)	4.5 (15)
174		320.2	329.9	223.9	6.2	1.0	7.1	48.8	3/T	1.03 (17)	4.5 (15)
AVG		317.1	328.3	227.6	6.1	1.0	6.8	48.0			
STD DEV		4.31	2.26	5.23	0.07	0.0	0.42	1.13			
% STD DEV		1.36	0.69	2.30	1.15	0.0	6.24	2.36			
175		324.9	333.5	239.7	5.3	0.8	5.8	45.3	2/T	1.60 (18)	4.5 (16)
179		325.5	334.7	237.7	4.0	0.8	5.8	44.7	3/T	1.78 (18)	4.5 (16)
AVG		325.2	334.1	238.0	4.6	0.8	5.8	45.0			
STD DEV		0.42	0.85	1.41	0.92	0.0	0.0	0.42			
% STD DEV		0.13	0.25	0.59	19.77	0.0	0.0	0.94			

ANSC Dwg. No. 1138265-120. Data to be used for material evaluation only. Do not use for design.

Table 5-5

TENSILE DATA FOR ALUMINUM 7075-T73 FORGING IRRADIATED AND TESTED AT 140°R

Crosshead Speed = 0.050 in./min (Specification M-21-1)

Specimen Number	Test Temp (°R)	Tensile Stress			% Elongation			% Area Reduct (Bench)	Fracture Location	Radiation Exposure	
						Chart				Neutron Fluence (n/cm^2)	
		0.2% Offset (ksi)	Max (ksi)	Fract (ksi)	Bench	To Max Stress	To Fract			E > 1 MeV	E < 0.48 eV
156		76.9	94.2	92.0	12.6	10.6	12.7	19.4	3/0	Control	
159		78.2	85.8	93.7	11.9	9.8	12.1	16.2	2/T	Control	
163		78.4	94.9	93.1	12.2	10.2	12.1	18.9	3/0	Control	
165		71.4	93.1	92.0	11.0	9.4	11.0	18.7	2/0	Control	
AVG		76.2	92.0	92.7	11.9	10.0	12.0	18.3			
STD DEV		3.28	4.20	0.85	0.68	0.52	0.71	1.43			
% STD DEV		4.31	4.56	0.91	5.70	5.16	5.92	7.82			
162		82.9	95.8	109.8	13.2	9.2	12.6	17.0	3/0	2.30 (17)	1.8 (16)
167		82.4	95.1	92.9	12.9	10.3	13.1	17.4	2/0	2.65 (17)	1.8 (16)
161		86.6	94.3	91.7	12.0	7.0	9.7	21.0	3/T	2.95 (17)	1.8 (16)
166		82.6	94.6	84.7	11.6	9.6	11.1	19.4	2/0	3.00 (17)	1.8 (16)
AVG		83.6	94.9	94.8	12.4	9.0	11.6	18.7			
STD DEV		1.99	0.66	10.65	0.75	1.42	1.54	1.86			
% STD DEV		2.38	0.69	11.24	6.04	15.78	13.24	9.94			
158		90.6	92.2	70.2	10.9	8.2	11.2	20.5	2/0	2.89 (18)	4.9 (16)
157		92.0	92.3	82.3	11.0	0.0	10.7	26.1	1/0	3.28 (18)	4.9 (16)
160		92.1	92.3	81.5	11.3	0.0	11.2	28.6	2/0	3.70 (18)	4.9 (16)
164		92.3	92.6	82.6	10.9	0.1	10.3	24.5	2/0	3.73 (18)	4.9 (16)
AVG		91.7	92.3	79.1	11.0	2.1	10.8	24.9			
STD DEV		0.78	0.17	5.98	0.19	4.08	0.44	3.40			
% STD DEV		0.85	0.19	7.56	1.72	196.80	4.02	13.63			

ANSC Dwg. No. 1138265-114. Data to be used for material evaluation only. Do not use for design.

Table 5-6

TENSILE DATA FOR AISI 9310 BAR IRRADIATED AND TESTED AT 140°R
(Specification M-31-1)

Crosshead Speed = 0.050 in./min

Specimen Number	Test Temp (°R)	Tensile Stress: 0.2% Offset (ksi)	Tensile Stress: Max (ksi)	Tensile Stress: Fract (ksi)	% Elongation: Bench	% Elongation: Chart: To Max Stress	% Elongation: Chart: To Fract	% Area Reduct (Bench)	Fracture Location	Radiation Exposure: Neutron Fluence (n/cm²): E > 1 MeV	Radiation Exposure: Neutron Fluence (n/cm²): E < 0.48 eV
1		220.9	250.8	201.5	13.9	5.2	14.1	43.2	2/T	Control	
7		222.7	254.1	184.3	13.4	5.1	13.1	52.6	2/T	Control	
AVG		221.7	252.5	192.9	13.7	5.2	13.6	47.9			
STD DEV		1.41	2.33	12.16	0.35	0.07	0.71	6.65			
% STD DEV		0.64	0.92	6.30	2.59	1.37	5.20	13.88			
6		226.3	256.0	200.1	11.8	5.2	12.0	46.2	3/T	2.40 (16)	1.8 (15)
4		228.8	256.2	189.9	12.4	5.1	13.1	50.8	2/T	2.60 (16)	1.8 (15)
3		226.1	255.7	197.5	13.1	4.6	13.6	47.8	2/T	2.80 (16)	1.8 (15)
AVG		227.1	256.0	195.8	12.4	5.0	12.9	48.3			
STD DEV		1.50	0.25	5.30	0.65	0.32	0.82	2.34			
% STD DEV		0.66	0.10	2.71	5.23	6.47	6.35	4.84			
2		225.9	253.6	181.6	11.8	4.2	11.9	53.9	2/T	2.30 (17)	1.8 (16)
8		224.5	257.6	172.0	12.5	4.0	12.7	58.7	3/T	2.65 (17)	1.8 (16)
5		225.7	256.5	165.3	13.2	4.5	13.9	59.6	2/T	3.00 (17)	1.8 (16)
AVG		225.4	255.9	173.0	12.5	4.2	12.8	57.4			
STD DEV		0.76	2.07	8.19	0.70	0.25	1.01	3.06			
% STD DEV		0.34	0.81	4.34	5.60	5.95	7.84	5.34			

ANSC Dwg. No. 1138265-117. Data to be used for material evaluation only. Do not use for design.

Table 5-7

TENSILE DATA FOR ARMCO ALLOY 22-13-5 WELDED FORGING IRRADIATED AND TESTED AT 140°R
(Specification M-38-1)

Crosshead Speed = 0.050 in./min

Specimen Number	Test Temp (°R)	Tensile Stress 0.2% Offset (ksi)	Tensile Stress Max (ksi)	Tensile Stress Fract (ksi)	% Elongation Bench	% Elongation Chart To Max Stress	% Elongation Chart To Fract	% Area Reduct (Bench)	Fracture Location	Radiation Exposure Neutron Fluence (n/cm²) E > 1 MeV	Radiation Exposure Neutron Fluence (n/cm²) E < 0.48 eV
2-3		111.0	155.5	155.5	14.7	13.1	13.1	21.9	2/T	2.30 (17)	1.8 (16)
6-3		111.0	161.1	161.1	13.5	12.1	12.1	18.4	2/T	2.65 (17)	1.8 (16)
1-3		107.0	162.9	162.9	17.4	16.8	16.8	19.6	1/T	3.00 (17)	1.8 (16)
AVG		109.0	159.8	159.8	15.2	14.0	14.0	20.0			
STD DEV		1.73	3.86	3.86	2.00	2.48	2.48	1.78			
% STD DEV		1.59	2.41	2.41	13.14	17.69	17.69	8.91			
1-4		141.1	185.0	185.0	14.8	14.3	14.3	15.7	3/T	2.89 (18)	4.9 (16)
6-4		150.9	189.0	189.0	10.8	8.9	8.9	15.3	3/T	3.28 (18)	4.9 (16)
2-4		144.3	182.6	182.6	14.5	13.1	13.1	25.9	2/T	3.70 (18)	4.9 (16)
AVG		145.4	185.5	185.5	13.4	12.1	12.1	19.0			
STD DEV		5.00	3.23	3.23	2.23	2.83	2.83	6.01			
% STD DEV		3.44	1.74	1.74	16.67	23.43	23.43	31.67			

ANSC Dwg. No. 1118388-3215. Data to be used for material evaluation only. Do not use for design.

Table 5-8

TENSILE DATA FOR ARMCO ALLOY 22-13-5 PLATE IRRADIATED AND TESTED AT 140°R
(Specification M-38-4)

Crosshead Speed = 0.050 in./min

Specimen Number	Test Temp (°R)	Tensile Stress 0.2% Offset (ksi)	Tensile Stress Max (ksi)	Tensile Stress Fract (ksi)	% Elongation Bench	% Elongation Chart To Max Stress	% Elongation Chart To Fract	% Area Reduct (Bench)	Fracture Location	Radiation Exposure Neutron Fluence (n/cm²) E > 1 MeV	Radiation Exposure Neutron Fluence (n/cm²) E < 0.48 eV
211		156.0	214.3	214.3	21.2	22.0	22.0	19.0	3/T	Control	
214		154.1	211.5	211.5	16.7	17.3	17.3	17.0	3/T	Control	
216		159.2	222.9	222.9	22.3	23.2	23.2	17.7	1/T	Control	
AVG		156.4	216.2	216.2	20.1	20.8	20.8	17.9			
STD DEV		2.58	5.94	5.94	2.97	3.12	3.12	1.01			
% STD DEV		1.65	2.75	2.75	14.79	14.97	14.97	5.67			
213		181.9	234.4	234.4	18.9	19.3	19.3	17.2	3/O	6.82 (17)	4.5 (16)
217		175.9	226.7	225.9	14.9	14.6	14.7	14.7	3/T	7.87 (17)	4.5 (16)
212		175.2	221.7	221.7	11.8	11.6	11.6	13.0	3/T	8.92 (17)	4.5 (16)
AVG		177.7	227.6	227.3	15.2	15.2	15.2	15.0			
STD DEV		3.68	6.40	6.47	3.56	3.88	3.87	2.11			
% STD DEV		2.07	2.81	2.85	23.42	25.6	25.5	14.12			
210		200.5	242.9	242.9	15.2	15.6	15.6	15.9	3/O	2.89 (18)	4.9 (16)
215		201.8	239.4	239.4	14.1	14.2	14.2	15.3	3/T	3.28 (18)	4.9 (16)
218		203.4	240.0	240.0	12.7	13.0	13.0	13.1	3/T	3.70 (18)	4.9 (16)
AVG		201.9	240.8	240.8	14.0	14.3	14.3	14.8			
STD DEV		1.45	1.87	1.87	1.25	1.30	1.30	1.47			
% STD DEV		0.72	0.78	0.78	8.95	9.12	9.12	9.98			

ANSC Dwg. No. 1138265-115. Data to be used for material evaluation only. Do not use for design.

Table 5-9-A

TENSILE DATA FOR UNNOTCHED TITANIUM 5Al 2.5Sn IRRADIATED AND TESTED AT 140°R
(Specification M-40-1)

Crosshead Speed = 0.050 in./min

Specimen Number	Test Temp (°R)	Tensile Stress 0.2% Offset (ksi)	Tensile Stress Max (ksi)	Tensile Stress Fract (ksi)	% Elongation Bench	% Elongation Chart To Max Stress	% Elongation Chart To Fract	% Area Reduct (Bench)	Fracture Location	Radiation Exposure Neutron Fluence (n/cm²) E > 1 MeV	Radiation Exposure Neutron Fluence (n/cm²) E < 0.48 eV
45		174.5	186.9	174.5	17.7	9.6	17.8	32.6	3/T	Control	
48		186.7	198.2	189.6	14.2	8.6	14.4	31.6	1/T	Control	
49		173.9	186.3	176.8	14.1	7.1	14.0	23.4	3/T	Control	
50		187.4	197.9	187.7	11.8	6.3	12.2	32.8	2/T	Control	
55		173.7	183.5	182.5	8.2	5.9	7.7	16.1	3/T	Control	
70		177.7	186.0	178.4	11.7	4.9	11.5	25.7	3/T	Control	
77		176.9	187.1	183.2	16.3	6.7	15.8	25.4	3/T	Control	
80		174.7	187.1	177.9	14.0	8.9	13.8	31.5	3/T	Control	
81		181.0	191.8	181.0	13.6	7.1	13.6	29.0	3/0	Control	
Avg		178.5	189.4	181.3	13.5	7.2	13.4	27.6			
Std Dev		5.4	5.3	5.0	2.8	1.5	2.8	5.5			
% Std Dev		3.0	2.8	2.8	20.4	21.1	21.1	20.0			
72		196.6	200.8	193.8	4.5	1.5	4.0	21.1	3/T	1.05(18)	4.9(16)
59		203.0	207.2	189.9	5.6	1.2	5.2	27.4	3/T	1.18(18)	4.9(16)
71		201.0	204.2	186.5	4.8	0.9	4.5	28.2	3/T	1.32(18)	4.9(16)
47		213.0	218.4	204.7	5.8	1.4	5.4	24.2	3/0	1.35(18)	4.9(16)
35		212.2	217.9	204.3	5.3	1.2	5.0	25.3	1/T	1.36(18)	4.9(16)
44		197.9	203.2	190.3	4.6	1.4	5.8	24.7	2/T	1.40(18)	4.9(16)
83		199.1	203.5	191.7	4.0	1.1	3.9	21.1	2/T	1.40(18)	4.9(16)
66		201.9	206.0	191.7	3.8	1.2	3.9	23.1	3/0	1.43(18)	4.9(16)
63		197.2	202.6	189.0	5.3	1.4	5.1	28.1	3/0	1.45(18)	4.9(16)
Avg		202.4	207.1	193.5	4.9	1.3	4.8	24.8			
Std Dev		6.2	6.5	6.5	0.7	0.2	0.7	2.7			
% Std Dev		3.0	3.2	3.4	14.3	15.0	14.8	11.1			
74		209.7	212.2	189.4	4.9	0.9	4.7	28.3	3/T	2.70(18)	4.5(16)
52		205.9	207.1	196.6	2.2	0.5	2.1	21.4	3/T	3.00(18)	4.5(16)
65		218.8	222.9	204.5	4.0	0.9	3.8	21.3	3/T	3.19(18)	4.5(16)
64		205.9	208.7	193.2	4.1	0.9	3.8	22.0	3/T	3.20(18)	4.5(16)
78		218.8	221.3	206.3	3.3	0.6	3.0	18.1	2/T	3.39(18)	4.5(16)
42		199.2	207.4	191.2	5.8	1.7	5.4	26.1	2/T	3.40(18)	4.5(16)
43		206.0	211.7	192.4	6.0	1.4	5.3	29.3	3/T	3.59(18)	4.5(16)
56		199.9	204.1	196.8	4.1	1.4	3.2	24.4	3/T	3.60(18)	4.5(16)
69		232.4	238.1	217.2	5.6	1.2	5.0	26.4	2/0	3.77(18)	4.5(16)
Avg		210.7	214.8	198.6	4.4	1.1	4.0	24.1			
Std Dev		10.7	10.8	9.0	1.3	0.4	1.1	3.7			
% Std Dev		5.1	5.0	4.6	28.2	37.6	28.4	15.3			

ANSC Dwg No. 1138265. Data to be used for material evaluation only. Do not use for design.

Table 5-9-B

TENSILE DATA FOR UNNOTCHED TITANIUM 5Al 2.5Sn ENCAPSULATED IN HYDROGEN GAS AND IRRADIATED AT 140°R AND TESTED AT 140°R
(Specification M-40-1)

Crosshead speed = 0.05 in./min

Specimen Number	Tensile Stress [a]			% Elongation			% Area Reduct (Bench)	Fracture Location	Radiation Exposure Neutron Fluence (n/cm^2)	
	0.2% Offset (ksi)	Max (ksi)	Fract (ksi)	Bench	Chart To Max Stress	Chart To Fract			E > 1 MeV	E < 0.48 eV
27	202.4	208.5	193.5	3.2	0.9	2.9	27.2	2/T	3.40(18)	4.5(16)
29	220.2	224.1	205.3	3.6	0.6	1.3	30.8	3/T	3.38(18)	4.5(16)
32	207.2	209.4	189.4	3.3	0.4	1.9	32.0	3/T	3.35(18)	4.5(16)
Ave	209.9	214.0	196.1	3.4	0.6	2.0	30.0			
Std Dev	9.21	8.76	8.25	0.21	0.25	0.81	2.50			
% Std Dev	4.39	4.09	4.21	6.18	39.74	39.75	8.33			
24	195.4	200.4	189.7	2.0	0.5	1.8	20.9	3/T	6.33(17)	4.9(16)
25	178.9	181.4	169.0	2.6	0.6	2.0	25.5	2/T	9.14(17)	4.9(16)
28	197.3	200.5	187.5	2.3	0.4	1.8	27.9	3/T	6.70(17)	4.9(16)
30	206.9	216.6	199.2	2.7	1.0	3.6	27.6	2/T	7.70(17)	4.9(16)
31	181.4	186.2	171.5	2.9	0.7	2.6	29.1	3/T	8.66(17)	4.9(16)
33	195.7	200.5	187.1	2.6	0.5	2.4	24.5	2/T	7.26(17)	4.9(16)
Ave	192.6	197.6	184.0	2.5	0.6	2.0	25.92			
Std Dev	10.56	12.47	11.55	0.32	0.2	1.0	2.97			
% Std Dev	5.48	6.31	6.28	12.67	34.65	47.95	11.48			

ANSC Dwg. No. 1138265. Data to be used for material evaluation only. Do not use for design.

[a]Area taken to be 0.0314 $in.^2$.

Table 5-10-A

TENSILE DATA FOR NOTCHED TITANIUM 5Al 2.5Sn IRRADIATED AND TESTED AT 140°R

(Specification M-40-1)

Crosshead Speed = 0.050 in/min

Specimen No.	Ave Notch Diam (in.)	Area at Notch ($in.^2$)	Fracture Load* (lb)	Fracture Stress (ksi)	Neutron Fluence (n/cm^2) E >1 MeV	E < 0.48 eV
9	0.1777	0.0248	6290	253.8	Control	
18	0.1824	0.0261	6160	235.7	Control	
19	0.1815	0.0259	6100	235.9	Control	
20	0.1829	0.0263	6140	233.8	Control	
27	0.1814	0.0258	6500	251.5	Control	
29	0.1818	0.0259	6150	237.0	Control	
37	0.1785	0.0250	5400	215.9	Control	
45	0.1823	0.0261	6600	253.0	Control	
Ave			6168	239.5		
Std Dev			360.0	12.8		
% Std Dev			5.8	5.4		
17	0.1824	0.0261	6150	235.5	1.12(18)	4.9(16)
34	0.1825	0.0262	6080	232.4	1.25(18)	4.9(16)
28	0.1826	0.0262	6310	241.0	1.34(18)	4.9(16)
43	0.1827	0.0262	6240	238.0	1.36(18)	4.9(16)
41	0.1806	0.0256	5620	219.4	1.38(18)	4.9(16)
26			>5000**	Off Scale	1.42(18)	4.9(16)
6	0.1822	0.0261	5900	226.3	1.42(18)	4.9(16)
44	0.1816	0.0259	5900	227.8	1.46(18)	4.9(16)
Ave			6029	231.5		
Std Dev			238.5	7.5		
% Std Dev			4.0	3.2		
31	0.1824	0.0261	5450	208.6	2.85(18)	4.5(16)
8	0.1784	0.0250	4550	182.0	3.10(18)	4.5(16)
21	0.1813	0.0258	4400	170.4	3.31(18)	4.5(16)

Table 5-10-A

TENSILE DATA FOR NOTCHED TITANIUM 5A1 2.5Sn IRRADIATED AND TESTED AT 140°R (Cont'd)

(Specification M-40-1)

Specimen No.	Ave Notch Diam (in.)	Area at Notch (in.^{2})	Fracture Load* (lb)	Fracture Stress (ksi)	Neutron Fluence (n/cm^2) E > 1 MeV	Neutron Fluence (n/cm^2) E < 0.48 eV
13	0.1826	0.0262	5620	214.7	3.29(18)	4.5(16)
35	0.1822	0.0261	6000	230.1	3.49(18)	4.5(16)
7	0.1809	0.0257	4810	187.2	3.50(18)	4.5(16)
30	0.1823	0.0261	5930	227.2	3.68(18)	4.5(16)
40	0.1816	0.0259	5790	223.5	3.85(18)	4.5(16)
Ave			5319	205.5		
Std Dev			639.4	22.7		
% Std Dev			12.0	11.1		

* Fracture load is same maximum load

** Not included in average

ANSC Dwg. No. 1139567. Data to be used for material evaluation only. Do not use for design.

Table 5-10-B

TENSILE DATA FOR NOTCHED TITANIUM 5Al 2.5Sn ENCAPSULATED IN HYDROGEN GAS AND IRRADIATED AT 140°R AND TESTED AT 140°R
(Specification M-40-1)

Crosshead speed = 0.05 in./min

Specimen No.	Max Load (lb)	Max Stress[a] (ksi)	Fracture Load (lb)	Fracture Stress[a] (ksi)	Neutron Fluence (n/cm^2) E >1 MeV	Neutron Fluence (n/cm^2) E < 0.48 eV
01	5360	206.2	5360	206.2	9.35(17)	4.9(16)
03	5080	195.4	5080	195.4	1.00(18)	4.9(16)
04	6380	245.4	6380	245.4	9.62(17)	4.9(16)
Ave		215.7		215.7		
Std Dev		26.3		26.3		
% Std Dev		12.2		12.2		
05	5050	194.2	5050	194.2	3.38(18)	4.5(16)
02	5380	206.9	5380	206.9	3.35(18)	4.5(16)
Ave		200.6		200.6		
Std Dev		8.98		8.98		
% Std Dev		4.48		4.48		

ANSC Dwg. No. 1139567. Data to be used for material evaluation only. Do not use for design.

[a]Area at notch taken to be 0.026 $in.^2$.

Table 5-11-A

TENSILE DATA FOR UNNOTCHED HASTELLOY X IRRADIATED AND TESTED AT 140°R
(Specification M-40-1)

Crosshead Speed = 0.050 in./min

Specimen Number	Test Temp (°R)	Tensile Stress: 0.2% Offset (ksi)	Tensile Stress: Max (ksi)	Tensile Stress: Fract (ksi)	% Elongation: Bench	% Elongation: Chart: To Max Stress	% Elongation: Chart: To Fract	% Area Reduct (Bench)	Fracture Location	Radiation Exposure: Neutron Fluence (n/cm^2): E > 1 MeV	Radiation Exposure: Neutron Fluence (n/cm^2): E < 0.48 eV
101		88.3	178.9	178.0	56.9	53.2	57.6	41.2	3/T	Control	
102		77.2	166.3	155.0	60.8	47.8	60.4	52.4	3/T	Control	
104		76.3	163.7	152.9	60.1	55.8	63.3	51.4	3/0	Control	
111		83.9	169.1	155.7	58.5	53.1	59.8	53.9	3/T	Control	
123		82.1	167.7	149.6	46.8	39.1	47.6	52.5	1/T	Control	
126		82.5	170.3	155.4	58.6	52.1	60.4	56.7	2/T	Control	
127		84.0	164.2	161.1	40.3	37.9	41.5	40.6	3/T	Control	
134		85.1	170.1	168.5	59.1	54.2	59.5	44.2	2/0	Control	
Avg		82.4	168.8	159.5	55.1	49.2	56.3	49.1			
Std Dev		4.0	4.8	9.4	7.4	7.0	7.6	6.2			
% Std Dev		4.8	2.8	5.9	13.4	14.2	13.5	12.6			
131[a]		122.5	178.7	177.7	48.7	43.5	50.5	40.3	3/0	7.9(17)	4.9(16)
124[a]		126.5	180.1	173.7	49.6	43.3	50.6	46.7	3/T	9.3(17)	4.9(16)
122[a]		128.0	180.3	179.0	44.3	41.7	45.6	41.7	3/T	1.06(18)	4.9(16)
114[a]		128.9	181.8	174.1	46.4	41.1	48.3	45.9	3/0	1.18(18)	4.9(16)
113[a]		132.4	181.4	177.4	44.9	38.6	45.8	53.4	3/T	1.27(18)	4.9(16)
Avg		127.7	180.5	176.4	46.8	41.6	48.2	45.6			
Std Dev		3.6	1.2	2.4	2.3	2.0	2.4	5.1			
% Std Dev		2.8	0.7	1.3	5.0	4.8	5.0	11.3			
129		151.1	211.4	192.5	46.5	42.2	47.5	50.9	3/T	1.33(18)	4.9(16)
116		149.0	205.9	199.8	43.5	39.5	44.7	45.3	3/T	1.42(18)	4.9(16)
115		142.2	204.9	194.7	48.6	46.0	49.5	47.2	3/T	1.35(18)	4.9(16)
106		150.9	210.2	190.2	46.6	41.2	47.0	53.4	3/T	1.43(18)	4.9(16)
Avg		148.3	208.1	194.3	46.3	42.2	47.2	49.2			
Std Dev		4.2	3.2	4.1	2.1	2.8	2.0	3.6			
% Std Dev		2.8	1.5	2.1	4.5	6.5	4.2	7.4			
97		157.9	192.6	183.2	44.7	32.1	40.1	44.2	3/T	3.70(18)	4.5(16)
139		159.1	194.1	187.7	37.2	32.0	38.3	41.7	3/T	3.85(18)	4.5(16)
133		156.9	191.8	182.3	39.9	30.4	42.3	45.4	2/T	3.92(18)	4.5(16)
117		159.9	193.9	178.0	39.2	28.2	33.5	50.2	3/T	4.02(18)	4.5(16)
132		155.4	190.2	182.3	37.4	31.7	38.6	43.3	3/T	4.04(18)	4.5(16)
121		158.9	194.5	185.6	37.6	30.9	38.9	44.2	3/T	4.06(18)	4.5(16)
142		157.1	191.4	183.7	38.7	30.9	39.7	45.1	3/T	4.13(18)	4.5(16)
141		162.1	198.2	183.3	35.8	31.4	36.6	50.5	3/T	4.24(18)	4.5(16)
143		159.1	194.2	183.8	36.0	29.8	37.2	46.2	3/T	4.25(18)	4.5(16)
Avg		158.5	193.4	183.3	38.5	30.8	38.4	45.6			
Std Dev		1.9	2.3	2.6	2.7	1.2	2.5	3.0			
% Std Dev		1.2	1.2	1.4	7.0	4.0	6.4	6.5			

ANSC Dwg. No. 1138265. Data to be used for material evaluation only. Do not use for design.

[a]This group of specimens was inadvertently warmed briefly during handling; the time/temperature profile is not known.

Table 5-11-B

TENSILE DATA FOR UNNOTCHED HASTELLOY X ENCAPSULATED IN HYDROGEN GAS AND IRRADIATED AT 140°R AND TESTED AT 140°R
(Specification M-40-1)

Crosshead Speed = 0.05 in./min

Specimen Number	Tensile Stress[a]			% Elongation			% Area Reduct (Bench)	Fracture Location	Radiation Exposure	
					Chart				Neutron Fluence (n/cm^2)	
	0.2% Offset (ksi)	Max (ksi)	Fract (ksi)	Bench	To Max Stress	To Fract			E > 1 MeV	E < 0.48 eV
86	139.1	181.4	173.8	21.9	21.5	23.2	44.0	4/T	3.35(18)	4.5(16)
90	148.9	192.9	187.8	23.5	22.8	25.3	44.4	3/T	3.38(18)	4.5(16)
93	143.2	192.6	184.6	22.2	17.6	22.6	48.0	3/T	3.40(18)	4.5(16)
Ave	143.7	189.0	182.1	22.5	20.6	23.7	45.5			
Std Dev	4.92	6.55	7.34	0.85	2.71	1.42	2.20			
% Std Dev	3.42	3.47	4.03	3.77	13.12	5.98	4.85			
84	124.1	180.8	173.4	34.1	26.7	30.1	48.4	3/T	1.53(18)	4.9(16)
85	121.9	181.6	178.5	29.6	28.6	31.3	44.8	3/T	1.19(18)	4.9(16)
87	121.3	175.0	165.5	30.3	27.8	32.6	50.7	1/T	1.37(18)	4.9(16)
88	116.2	167.1	161.0	26.9	24.0	28.7	48.3	3/T	1.96(18)	4.9(16)
89	127.3	184.6	184.0	26.7	24.0	28.5	37.5	2/T	1.81(18)	4.9(16)
91	125.4	183.8	176.5	27.5	26.8	29.1	42.7	2/T	12.6(18)	4.9(16)
92	116.5	179.7	175.4	29.7	28.7	31.2	44.8	3/T	1.10(18)	4.9(16)
Ave	121.8	178.9	173.5	29.3	26.7	30.2	45.3			
Std Dev	4.22	6.09	7.83	2.58	1.97	1.55	4.39			
% Std Dev	3.47	3.40	4.52	8.83	7.41	5.11	9.70			

ANSC Dwg. No. 1138265. Data to be used for material evaluation only. Do not use for design.
[a]Area taken to be 0.0314 $in.^2$.

Table 5-12-A

TENSILE DATA FOR NOTCHED HASTELLOY X IRRADIATED AND TESTED AT 140°R

(Specification M-40-1)

Crosshead Speed = 0.050 in./min

Specimen No.	Ave Notch Diam. (in.)	Area at Notch ($in.^2$)	Max Load (lb)	Max Stress (ksi)	Fracture Load (lb)	Fracture Stress (ksi)	Neutron Fluence (n/cm^2) E > 1 MeV	Neutron Fluence (n/cm^2) E < 0.48 eV
54	0.1820	0.0260	4620	177.7	4500	173.1	Control	
57	0.1819	0.0260	4670	178.8	4550	175.2	Control	
61	0.1821	0.0260	4520	173.6	4300	165.2	Control	
64	0.1820	0.0260	4610	177.3	4500	173.1	Control	
66	0.1814	0.0258	4470	173.0	4300	166.4	Control	
68	0.1821	0.0260	4480	172.0	4250	163.2	Control	
76	0.1820	0.0260	4510	173.5	4400	169.2	Control	
77	0.1821	0.0260	4430	170.1	4250	163.2	Control	
Ave			4539	174.5	4381	168.6		
Std Dev			84.6	3.1	122.3	4.8		
% Std Dev			1.9	1.8	2.8	2.8		
72[a]	0.1828	0.0262	5400	205.8	5300	201.9	8.50(17)	4.9(16)
80[a]	0.1816	0.0259	5500	212.3	4500	173.7	1.00(18)	4.9(16)
53[a]	0.1818	0.0259	5590	215.5	5400	208.1	1.14(18)	4.9(16)
67[a]	0.1822	0.0261	5660	217.2	5500	211.1	1.20(18)	4.9(16)
Ave			5537	212.7	5175	198.7		
Std Dev			112.7	5.0	457.4	17.1		
% Std Dev			2.0	2.4	8.8	8.6		
62	0.1821	0.0260	6600	253.6	6450	247.8	1.30(18)	4.9(16)
75	0.1823	0.0261	6590	252.5	6480	248.3	1.35(18)	4.9(16)
90	0.1819	0.0260	6230	239.7	6100	234.7	1.42(18)	4.9(16)
89	0.1825	0.0262	6630	253.5	6500	248.5	1.44(18)	4.9(16)
Ave			6512	249.8	6382	244.8		
Std Dev			189.1	6.8	189.5	6.8		
% Std Dev			2.9	2.7	3.0	2.8		
84	0.1821	0.0260	6630	254.6	6450	247.7	3.80(18)	4.5(16)
51	0.1819	0.0260	6630	255.1	6500	250.1	3.95(18)	4.5(16)
83	0.1820	0.0260	6590	253.3	6400	246.0	3.98(18)	4.5(16)
70	0.1827	0.0262	6650	253.8	6450	246.2	4.04(18)	4.5(16)

[a]This group of specimens was inadvertently warmed briefly during handling; the time-temperature profile is not known.

Table 5-12-A

TENSILE DATA FOR NOTCHED HASTELLOY X IRRADIATED AND TESTED AT 140°R (Cont'd)

(Specification M-40-1)

Specimen No.	Ave Notch Diam. (in.)	Area at Notch ($in.^2$)	Max Load (lb)	Max Stress (ksi)	Fracture Load (lb)	Fracture Stress (ksi)	Neutron Fluence (n/cm^2) E >1 MeV	Neutron Fluence (n/cm^2) E < 0.48 eV
56	0.1818	0.0260	6600	254.3	6450	248.5	4.08(18)	4.5(16)
69	0.1819	0.0260	6490	249.7	6300	242.4	4.08(18)	4.5(16)
59	0.1819	0.0260	6500	250.1	6300	242.4	4.19(18)	4.5(16)
87	0.1822	0.0261	6880	263.9	6800	260.8	4.29(18)	4.5(16)
Ave			6621	254.4	6456	248.0		
Std Dev			120.3	4.4	156.8	5.8		
% Std Dev			1.8	1.7	2.4	2.4		

ANSC Dwg. No. 1139567. Data to be used for material evaluation only. Do not use for design.

Table 5-12-B

TENSILE DATA FOR NOTCHED HASTELLOY X ENCAPSULATED IN HYDROGEN GAS AND IRRADIATED AT 140°R AND TESTED AT 140°R
(Specification M-40-1)

Crosshead speed = 0.05 in./min

Specimen No.	Max Load (lb)	Max Stress[a] (ksi)	Fracture Load (lb)	Fracture Stress[a] (ksi)	Neutron Fluence (n/cm^2)	
					E > 1 MeV	E < 0.48 eV
47	5480	221.5	5280	213.8	2.09(18)	4.9(16)
48	5760	210.8	5560	203.1	2.10(18)	4.9(16)
Ave		216.2		208.4		
Std Dev		7.57		7.57		
% Std Dev		3.50		3.63		
46	6250	240.0	6100	234.6	3.35(18)	4.5(16)

ANSC Dwg. No. 1139567. Data to be used for material evaluation only. Do not use for design.

[a]Area at notch taken to be 0.026 in.^{2}.

Table 5-13

TENSILE DATA FOR UNNOTCHED ALUMINUM 6061-T61 (DM-320) IRRADIATED AT 140°R AND TESTED AT 140°, 340°, and 540°R
(Specification RTS-60 and M-40-1)

Crosshead Speed = 0.050 in./min

Specimen Number	Test Temp (°R)	Tensile Stress 0.2% Offset (ksi)	Tensile Stress Max (ksi)	Tensile Stress Fract (ksi)	% Elongation Bench	% Elongation Chart To Max Stress	% Elongation Chart To Fract	% Area Reduct (Bench)	Fracture Location	Radiation Exposure Neutron Fluence (n/cm^2) E > 1 MeV	Radiation Exposure Neutron Fluence (n/cm^2) E < 0.48 eV
701	140	50.2	62.6	62.3	7.8	6.9	7.0	15.4	2/T	Control	
702	140	48.8	63.2	62.3	9.5	8.6	8.7	17.1	4/T	Control	
703	140	47.2	61.6	60.8	9.5	8.5	8.7	17.5	1/T	Control	
704	140	55.6	70.1	70.1	8.6	8.3	8.3	10.2	3/0	Control	
741	140	47.6	58.6	57.2	7.1	6.3	6.4	16.0	3/T	Control	
742	140	47.8	61.0	61.0	7.8	6.8	6.8	21.3	3/T	Control	
743	140	46.0	58.8	58.8	7.8	7.3	7.3	21.3	3/0	Control	
744	140	48.6	59.8	59.8	6.8	6.4	6.4	15.8	2/T	Control	
Avg		49.0	62.0	61.5	8.1	7.4	7.5	16.8			
Std Dev		2.9	3.7	3.9	1.0	0.9	1.0	3.6			
% Std Dev		6.0	6.0	6.3	12.4	12.8	13.1	21.1			
745	340	45.7	54.2	53.8	8.3	7.6	8.1	13.0	3/0	Control	
746	340	44.7	51.9	51.3	6.5	5.4	6.2	17.2	2/T	Control	
Avg		45.2	53.1	52.6	7.4	6.5	7.2	15.1			
Std Dev		0.7	1.6	1.8	1.3	1.6	1.3	3.0			
% Std Dev		1.6	3.1	3.4	17.2	23.9	18.8	19.7			
747	540	42.3	48.8	48.1	8.6	7.6	8.1	16.9	3/0	Control	
748	540	41.9	49.1	48.4	9.5	7.3	8.6	16.1	1/0	Control	
Avg		42.1	49.1	48.3	9.1	7.5	8.4	16.5			
Std Dev		0.3	0.2	0.2	0.6	0.2	0.4	0.6			
% Std Dev		0.7	0.4	0.4	7.0	2.8	4.2	3.4			
735	140	70.1	72.4	71.7	3.9	3.3	3.5	15.5	3/T	1.03(18)	4.92(16)
734	140	62.1	63.8	62.4	6.1	3.0	5.6	17.5	2/T	1.10(18)	4.92(16)
733	140	68.3	70.4	69.6	8.1	6.5	7.0	11.5	3/T	1.12(18)	4.92(16)
732	140	60.7	61.8	59.1	4.7	1.7	4.2	16.3	2/T	1.15(18)	4.92(16)
752	140	62.1	64.2	63.5	2.6	2.0	2.3	17.6	1/T	1.20(18)	4.92(16)
751	140	63.5	66.4	66.4	5.3	4.6	4.7	13.7	2/T	1.32(18)	4.92(16)
749	140	65.2	67.1	66.8	4.4	3.5	3.6	12.8	1/T	1.35(18)	4.92(16)
750	140	62.8	64.1	63.0	4.6	2.7	4.0	14.6	2/T	1.41(18)	4.92(16)
Avg		64.4	66.3	65.3	5.0	3.4	4.4	14.9			
Std Dev		3.3	3.6	4.1	1.6	1.5	1.4	2.2			
% Std Dev		5.1	5.4	6.3	32.7	45.1	32.8	14.7			
762	340	51.0	54.8	54.4	8.4	6.7	7.7	15.6	1/T	7.60(17)	3.35(16)
761	340	51.4	54.9	54.4	5.4	4.0	5.2	14.2	2/0	7.75(17)	3.35(16)
Avg		51.2	54.9	54.4	6.9	5.4	6.5	14.9			
Std Dev		0.3	0.1	0.0	2.1	1.9	1.8	1.0			
% Std Dev		0.6	0.1	0.0	30.7	35.7	27.4	6.6			

WANL Dwg. No. 389D082H01. Data to be used for material evaluation only. Do not use for design.

Table 5-13 (cont'd)

Specimen Number	Test Temp (^oR)	Tensile Stress: 0.2% Offset (ksi)	Tensile Stress: Max (ksi)	Tensile Stress: Fract (ksi)	% Elongation: Bench	% Elongation: Chart: To Max Stress	% Elongation: Chart: To Fract	% Area Reduct (Bench)	Fracture Location	Radiation Exposure: Neutron Fluence (n/cm^2): E > 1 MeV	Radiation Exposure: Neutron Fluence (n/cm^2): E < 0.48 eV
764	540	42.1	45.9	44.6	8.7	3.7	5.0	20.4	1/0	7.20(17)	3.35(16)
763	540	41.1	46.0	45.8	10.5	9.1	9.7	13.0	3/T	7.40(17)	3.35(16)
Avg		41.6	46.0	45.2	9.6	6.4	7.4	16.7			
Std Dev		0.7	0.1	0.8	1.3	3.8	3.3	5.2			
% Std Dev		1.7	0.2	1.9	13.3	59.7	45.2	31.3			
757	140	70.7	70.9	67.7	2.5	0.3	2.2	12.6	2/0	4.30(18)	4.47(16)
758	140	73.7	73.7	71.7	2.5	0.4	2.0	10.3	3/0	4.35(18)	4.47(16)
759	140	69.6	69.8	68.0	2.1	0.4	1.5	13.1	3/0	4.33(18)	4.47(16)
760	140	79.8	79.8	77.7	2.5	0.4	2.1	9.8	3/0	4.33(18)	4.47(16)
740	140	73.0	73.0	69.0	3.7	0.2	3.3	17.8	2/T	4.35(18)	4.47(16)
739	140	71.0	71.1	66.8	2.8	0.3	2.3	12.1	3/0	4.43(18)	4.47(16)
738	140	67.4	67.4	65.9	2.9	0.2	2.1	15.2	3/T	4.44(18)	4.47(16)
737	140	70.2	70.5	68.8	3.9	0.6	3.5	10.2	3/0	4.40(18)	4.47(16)
736	140	67.9	68.1	65.7	2.6	0.4	2.3	14.4	2/T	4.30(18)	4.47(16)
Avg		71.5	71.6	69.0	2.8	0.4	2.4	12.8			
Std Dev		3.7	3.7	3.7	0.6	0.1	0.6	2.6			
% Std Dev		5.2	5.1	5.4	21.0	34.8	26.8	20.6			

Table 5-14
TENSILE DATA FOR NOTCHED ALUMINUM 6061-T61 (DM-320) IRRADIATED AND TESTED AT 140°R
(Specification RTS-60 and M-40-1)

Crosshead Speed = 0.050 in./min

Specimen No.	Ave Notch Diam (in.)	Area at Notch (in.^{2})	Fracture Load* (lb)	Fracture Stress (ksi)	Neutron Fluence (n/cm^2) E > 1 MeV	E < 0.48 eV
801	0.1827	0.0262	1990	75.9	Control	
802	0.1823	0.0261	2010	77.0	Control	
803	0.1826	0.0262	2235	85.3	Control	
804	0.1829	0.0263	2110	80.3	Control	
822	0.1827	0.0262	2045	78.0	Control	
823	0.1827	0.0262	2060	78.6	Control	
824	0.1833	0.0264	2100	79.6	Control	
Ave			2079	79.2		
Std Dev			81.6	3.1		
% Std Dev			3.9	3.9		
813	0.1831	0.0263	2360	89.7	1.18(18)	4.9(16)
814	0.1833	0.0264	2480	94.0	1.12(18)	4.9(16)
815	0.1825	0.0261	2610	99.8	1.11(18)	4.9(16)
816	0.1829	0.0263	2305	87.7	1.07(18)	4.9(16)
825	0.1826	0.0262	2330	89.0	1.25(18)	4.9(16)
826	0.1826	0.0762	2300	87.8	1.41(18)	4.9(16)
827	0.1826	0.0262	2350	89.7	1.38(18)	4.9(16)
828	0.1818	0.0259	2285	88.1	1.25(18)	4.9(16)
Ave			2378	90.7		
Std Dev			111.9	4.2		
% Std Dev			4.7	4.6		
817	0.1823	0.0261	2580	98.8	4.35(18)	4.5(16)
818	0.1828	0.0262	2510	99.5	4.42(18)	4.5(16)
819	0.1829	0.0263	2500	95.2	4.46(18)	4.5(16)
820	0.1831	0.0263	2375	90.2	4.40(18	4.5(16)
829	0.1823	0.0261	2580	98.9	4.25(18)	4.5(16)

Table 5-14

TENSILE DATA FOR NOTCHED ALUMINUM 6061-T61 (DM-320) IRRADIATED AND TESTED AT 140°R (Cont'd)

(Specification RTS-60 and M-40-1)

Specimen No.	Ave Notch Diam (in.)	Area at Notch ($in.^2$)	Fracture Load* (lb)	Fracture Stress (ksi)	Neutron Fluence (n/cm^2) E >1 MeV	Neutron Fluence (n/cm^2) E < 0.48 eV
830	0.1834	0.0264	2395	90.7	4.32(18)	4.5(16)
831	0.1828	0.0262	2325	88.6	4.34(18)	4.5(16)
832	0.1829	0.0263	2675	101.9	4.33(18)	4.5(16)
Ave			2493	95.5		
Std Dev			119.7	5.0		
% Std Dev			4.8	5.3		

* Fracture load is same as maximum load.

WANL Dwg. No. 389D084 H01. Data to be used for material evaluation only. Do not use for design.

Table 5-15

TENSILE DATA FOR UNWELDED ALUMINUM 5086-H-34 (DM-311) SHEET IRRADIATED AT 140°R AND TESTED AT SEVERAL TEMPERATURES
(Specification RTS-62)

Crosshead Speed = 0.050 in./min

Specimen Number	Test Temp (°R)	Tensile Stress			% Elongation			% Area Reduct (Bench)	Fracture Location	Radiation Exposure	
		0.2% Offset (ksi)	Max (ksi)	Fract (ksi)	Bench	Chart				Neutron Fluence (n/cm^2)	
						To Max Stress	To Fract			E > 1 MeV	E < 0.48 eV
219	140	48.0	69.1	63.4	31.2	24.1	32.3	28.1		Control	
227	140	44.1	68.2	62.3	32.7	23.8	33.8	29.6		Control	
236	140	48.2	70.6	65.8	32.8	23.6	33.5	28.8		Control	
Ave		46.8	69.3	63.8	32.2	23.8	33.2	28.8			
Std Dev		2.3	1.2	1.8	0.9	0.3	0.8	0.8			
% Std Dev		4.9	1.7	2.8	2.8	1.1	2.4	2.6			
237	340	39.1	51.8	44.3	17.4	11.0	17.7	21.3		Control	
246	340	38.6	51.9	43.7	17.2	12.1	17.1	20.7		Control	
250	340	39.3	51.9	52.0	16.3	11.9	16.2	19.7		Control	
Ave		39.0	51.9	46.7	17.0	11.7	17.0	20.6			
Std Dev		0.4	0.1	4.6	0.6	0.6	0.8	0.8			
% Std Dev		0.9	0.1	9.9	3.5	5.0	4.4	3.9			
201	540	39.0	51.1	46.3	9.1	8.9	11.2	13.0		Control	
212	540	39.9	52.4	47.6	10.5	7.8	10.3	11.0		Control	
214	540	37.8	51.4	45.9	11.1	9.2	10.5	11.2		Control	
Ave		38.9	51.6	46.6	10.2	8.6	10.7	11.7			
Std Dev		1.1	0.7	0.9	1.0	0.7	0.5	1.1			
% Std Dev		2.7	1.3	1.9	10.0	8.5	4.4	9.4			
255	740	36.7	41.7	35.7	18.2	5.5	18.2	33.8		Control	
263	740	35.6	40.8	33.5	17.9	4.5	18.1	35.6		Control	
266	740	36.3	41.1	34.1	16.3	4.1	16.8	32.6		Control	
Ave		36.2	41.2	34.4	17.5	4.7	17.7	34.0			
Std Dev		0.6	0.5	1.1	1.0	0.7	0.8	1.5			
% Std Dev		1.5	1.1	3.3	5.8	15.3	4.4	4.4			
221	140	65.7	73.3	68.1	23.7	14.4	22.8	59.0		3.9(17)	1.8(16)
226	140	64.7	73.2	68.6	20.9	14.5	20.7	59.3		3.9(17)	1.8(16)
230	140	65.0	71.4	65.6	24.1	14.2	23.8	27.3		3.9(17)	1.8(16)
Ave		65.1	72.5	67.4	22.9	14.4	22.4	48.5			
Std Dev		0.5	1.1	1.6	1.7	0.2	1.6	18.4			
% Std Dev		0.8	1.5	2.4	7.6	1.1	7.1	37.9			
239	340	46.7	53.5	45.2	16.1	10.6	14.6	21.9		3.9(17)	1.8(16)
243	340	44.1	52.4	44.7	15.4	10.1	14.4	20.3		3.9(17)	1.8(16)
254	340	47.9	53.5	44.7	15.6	9.8	14.5	23.4		3.9(17)	1.8(16)
Ave		46.2	53.1	44.9	15.7	10.2	14.5	21.9			
Std Dev		1.9	0.6	0.3	0.4	0.4	0.1	1.6			
% Std Dev		4.2	1.2	0.6	2.3	4.0	0.7	7.1			

WANL Dwg No. 100E445 H01. Data to be used for material evaluation only. Do not use for design.

Table 5-15 (cont'd)

Specimen Number	Test Temp (°R)	Tensile Stress: 0.2% Offset (ksi)	Tensile Stress: Max (ksi)	Tensile Stress: Fract (ksi)	% Elongation: Bench	% Elongation: Chart: To Max Stress	% Elongation: Chart: To Fract	% Area Reduct (Bench)	Fracture Location	Radiation Exposure: Neutron Fluence (n/cm^2): E > 1 MeV	Radiation Exposure: Neutron Fluence (n/cm^2): E < 0.48 eV
203	540	38.5	50.5	45.9	11.7	10.0	10.9	20.2		3.9(17)	1.8(16)
210	540	39.6	51.2	46.8	11.5	10.1	11.0	21.4		3.9(17)	1.8(16)
217	540	40.1	51.0	48.7	9.7	8.3	9.1	14.1		3.9(17)	1.8(16)
Ave		39.4	50.9	47.1	11.0	9.5	10.3	18.6			
Std Dev		0.8	0.4	1.4	1.1	1.0	1.1	3.9			
% Std Dev		2.1	0.7	3.0	10.0	10.7	10.3	21.1			
257	740	35.3	40.7	33.7	21.9	5.2	21.7	42.8		3.9(17)	1.8(16)
264	740	36.6	41.3	34.0	19.4	3.9	19.5	37.4		3.9(17)	1.8(16)
270	740	35.1	41.5	33.2	28.9	5.3	28.9	39.9		3.9(17)	1.8(16)
289	740	37.4	44.7	37.6	22.0	5.8	22.0	29.0			
Ave		36.1	42.1	34.6	23.1	5.1	23.0	37.3			
Std Dev		1.1	1.8	2.0	4.1	0.8	4.1	5.9			
% Std Dev		3.0	4.3	5.8	17.7	16.0	17.7	15.9			
220	140	75.9	78.9	72.3	12.4	0.6	11.9	21.5		1.84(18)	4.9(16)
232	140	79.9	77.7	74.9	9.0	0.3	8.8	4.7*		1.84(18)	4.9(16)
235	140	73.3	76.0	71.9	16.0	0.3	15.1	22.4		1.84(18)	4.9(16)
Ave		76.4	77.5	73.0	12.5	0.4	11.9	22.0			
Std Dev		3.3	1.5	1.6	3.5	0.2	3.2	0.6			
% Std Dev		4.4	1.9	2.2	28.1	43.3	26.4	2.9			
238	340	48.8	53.4	44.6	13.4	8.9	12.7	21.1		1.84(18)	4.9(16)
245	340	51.8	55.1	45.1	12.3	6.5	13.4	18.9		1.84(18)	4.9(16)
251	340	50.9	53.5	44.5	13.0	7.9	12.2	20.9		1.84(18)	4.9(16)
Ave		50.5	54.0	44.7	12.9	7.8	12.8	20.3			
Std Dev		1.5	1.0	0.3	0.6	1.2	0.6	1.2			
% Std Dev		3.0	1.8	0.7	4.3	15.5	4.7	6.0			
202	540	44.0	52.9	49.0	10.0	7.7	8.7	13.5		1.84(18)	4.9(16)
207	540	45.1	53.2	49.2	9.1	7.3	8.4	10.4		1.84(18)	4.9(16)
211	540	45.2	54.0	49.9	9.8	7.8	8.9	14.1		1.84(18)	4.9(16)
Ave		44.8	53.4	49.4	9.6	7.6	8.7	12.7			
Std Dev		0.7	0.6	0.5	0.5	0.3	0.3	2.0			
% Std Dev		1.5	1.1	1.0	4.9	3.5	2.9	15.7			
256	740	35.6	41.5	34.6	19.3	5.1	20.1	41.5		1.84(18)	4.9(16)
261	740	35.1	40.3	33.8	18.5	4.3	18.4	39.9		1.84(18)	4.9(16)
271	740	35.1	40.9	34.8	18.4	4.8	18.1	36.4		1.84(18)	4.9(16)
Ave		35.3	40.9	34.4	18.7	4.7	18.9	39.3			
Std Dev		0.3	0.6	0.5	0.5	0.4	1.1	2.6			
% Std Dev		0.8	1.5	1.5	2.6	8.5	5.7	6.6			

* not used in average

Table 5-16

TENSILE DATA FOR WELDED ALUMINUM 5086-H-34 (DM-311) SHEET IRRADIATED AT 140°R AND TESTED AT SEVERAL TEMPERATURES
(Specification RTS-62)

Crosshead Speed = 0.050 in./min

Specimen Number	Test Temp (°R)	Tensile Stress: 0.2% Offset (ksi)	Tensile Stress: Max (ksi)	Tensile Stress: Fract (ksi)	% Elongation: Bench	% Elongation: Chart To Max Stress	% Elongation: Chart To Fract	% Area Reduct (Bench)	Fracture Location	Radiation Exposure, Neutron Fluence (n/cm²): E > 1 MeV	Radiation Exposure, Neutron Fluence (n/cm²): E < 0.48 eV
224	140	28.7	56.2	55.5	15.8	14.3	14.6	25.5		Control	
229	140	24.7	52.8	52.8	10.9	8.0	8.0	15.9		Control	
234	140	26.2	44.4	38.7	5.4	2.8	3.9	11.2		Control	
Ave		26.5	51.1	49.0	10.7	8.4	8.8	17.5			
Std Dev		2.0	6.1	9.0	5.2	5.8	5.4	7.3			
% Std Dev		7.6	11.9	18.4	48.6	68.8	61.1	41.6			
240	340	21.5	36.1	33.0	5.8	3.8	4.5	12.6		Control	
252	340	21.2	39.9	38.3	7.9	5.4	6.1	13.9		Control	
Ave		21.4	38.0	35.7	6.9	4.6	5.3	13.3			
Std Dev		0.2	2.7	3.7	1.5	1.1	1.1	0.9			
% Std Dev		1.0	7.1	10.5	21.7	24.6	21.3	6.9			
206	540	20.5	36.5	35.4	6.3	3.7	4.3	24.4		Control	
208	540	24.4	42.2	40.5	8.2	6.1	7.2	20.6		Control	
218	540	24.0	41.0	39.1	14.1	5.3	6.0	27.2		Control	
Ave		23.0	39.9	38.3	9.5	5.0	5.8	24.1			
Std Dev		2.1	3.0	2.6	4.1	1.2	1.5	3.3			
% Std Dev		9.3	7.5	6.9	42.7	24.3	25.0	13.8			
258	740	21.8	28.6	27.2	1.5	1.3	1.8	9.4		Control	
267	740	21.7	27.8	25.0	2.0	1.3	1.8	13.9		Control	
Ave		21.8	28.2	26.1	1.8	1.3	1.8	11.7		Control	
Std Dev		0.1	0.6	1.6	0.4	0.0	0.0	3.2			
% Std Dev		0.3	2.0	6.0	20.2	0.0	0.0	27.3			
222	140	49.1	54.7	52.2	3.4	2.2	2.6	10.0		3.9(17)	1.8(16)
231	140	49.4	51.7	50.6	2.2	0.6	0.8	43.0		3.9(17)	1.8(16)
233	140	50.0	60.4	59.0	4.6	3.3	3.5	35.2		3.9(17)	1.8(16)
Ave		49.5	55.6	53.9	3.4	2.0	2.3	29.4			
Std Dev		0.5	4.4	4.5	1.2	1.4	1.4	17.2			
% Std Dev		0.9	7.9	8.3	35.3	66.8	59.8	58.7			
242	340	32.8	43.0	39.9	6.6	4.0	5.1	16.3		3.9(17)	1.8(16)
247	340	26.7	27.2	25.0	2.0	0.5	1.1	0.8		3.9(17)	1.8(16)
249	340	29.5	41.9	38.3	6.7	4.2	5.4	19.6		3.9(17)	1.8(16)
Ave		29.7	37.4	34.4	5.1	2.9	3.9	12.2			
Std Dev		3.1	8.8	8.2	2.7	2.1	2.4	10.0			
% Std Dev		10.3	23.6	23.8	52.6	71.8	62.1	82.1			

WANL Dwg No. 100E445 G02. Data to be used for material evaluation only. Do not use for design.

Table 5-16 (cont'd)

Specimen Number	Test Temp (°R)	Tensile Stress: 0.2% Offset (ksi)	Tensile Stress: Max (ksi)	Tensile Stress: Fract (ksi)	% Elongation: Bench	% Elongation: Chart: To Max Stress	% Elongation: Chart: To Fract	% Area Reduct (Bench)	Fracture Location	Radiation Exposure: Neutron Fluence (n/cm^2): E > 1 MeV	Radiation Exposure: Neutron Fluence (n/cm^2): E < 0.48 eV
204	540	26.1	41.1	40.0	6.5	3.9	4.3	26.6		3.9(17)	1.8(16)
209	540	22.5	34.2	32.8	5.1	3.0	3.8	9.6		3.9(17)	1.8(16)
215	540	21.8	31.6	22.1	3.8	2.2	3.1	27.8		3.9(17)	1.8(16)
Ave		23.5	35.6	31.6	5.1	3.0	3.7	21.3			
Std Dev		2.3	4.9	9.0	1.4	0.9	0.6	10.2			
% Std Dev		9.8	3.8	28.5	26.3	28.0	16.1	47.7			
260	740	22.3	31.7	28.7	3.1	3.7	5.5	21.2		3.9(17)	1.8(16)
265	740	22.2	31.5	29.7	2.5	2.7	3.3	26.5		3.9(17)	1.8(16)
272	740	24.9	36.0	34.4	7.7	4.6	6.8	38.8		3.9(17)	1.8(16)
Ave		23.1	33.1	30.9	4.4	3.7	5.2	28.8			
Std Dev		1.5	2.5	3.0	2.8	1.0	1.8	9.0			
% Std Dev		6.5	7.7	9.8	64.2	25.9	34.0	31.3			
223	140	53.5	53.5	53.0	0.8	0.2	0.4	17.9		1.84(18)	4.9(16)
225*	140	-	50.4	50.4	1.6	0.1	0.1	0.0		1.84(18)	4.9(16)
228	140	60.2	62.8	60.3	3.6	1.4	2.0	16.9		1.84(18)	4.9(16)
Ave		56.9	58.2	56.7	2.2	0.8	1.2	17.4			
Std Dev		4.7	6.6	5.2	2.0	0.8	1.1	0.7			
% Std Dev		8.3	11.3	9.1	90.0	106.1	94.3	4.1			
241	340	35.3	41.5	40.7	3.4	2.4	2.7	7.8		1.84(18)	4.9(16)
248	340	32.8	36.9	21.5	4.3	1.7	3.0	14.8		1.84(18)	4.9(16)
253	340	32.5	37.4	21.5	4.2	2.0	3.4	18.2		1.84(18)	4.9(16)
Ave		33.5	38.6	27.9	4.0	2.0	3.0	13.6			
Std Dev		1.5	2.5	11.1	0.5	0.4	0.4	5.3			
% Std Dev		4.6	6.5	39.7	12.4	17.3	11.6	39.0			
205	540	26.7	38.8	37.6	4.6	3.4	3.7	17.0		1.84(18)	4.9(16)
213	540	29.4	38.2	36.0	3.0	1.9	2.2	6.9		1.84(18)	4.9(16)
216	540	28.9	39.9	38.7	4.8	2.5	2.9	11.6		1.84(18)	4.9(16)
Ave		28.3	39.0	37.4	4.1	2.6	2.9	11.8			
Std Dev		1.4	0.9	1.4	1.0	0.8	0.8	5.1			
% Std Dev		5.1	2.2	3.6	23.9	29.0	25.6	42.7			
259	740	23.5	36.1	34.4	6.4	4.5	5.9	28.0		1.84(18)	4.9(16)
262	740	24.9	32.5	31.6	4.2	3.0	3.5	28.9		1.84(18)	4.9(16)
268	740	24.0	33.9	31.3	6.9	4.5	6.5	37.2		1.84(18)	4.9(16)
Ave		24.1	34.2	32.4	5.8	4.0	5.3	31.4			
Std Dev		0.7	1.8	1.7	1.4	0.9	1.6	5.1			
% Std Dev		2.9	5.3	5.3	24.6	21.7	30.0	16.2			

*No yield point. Data not included in average.

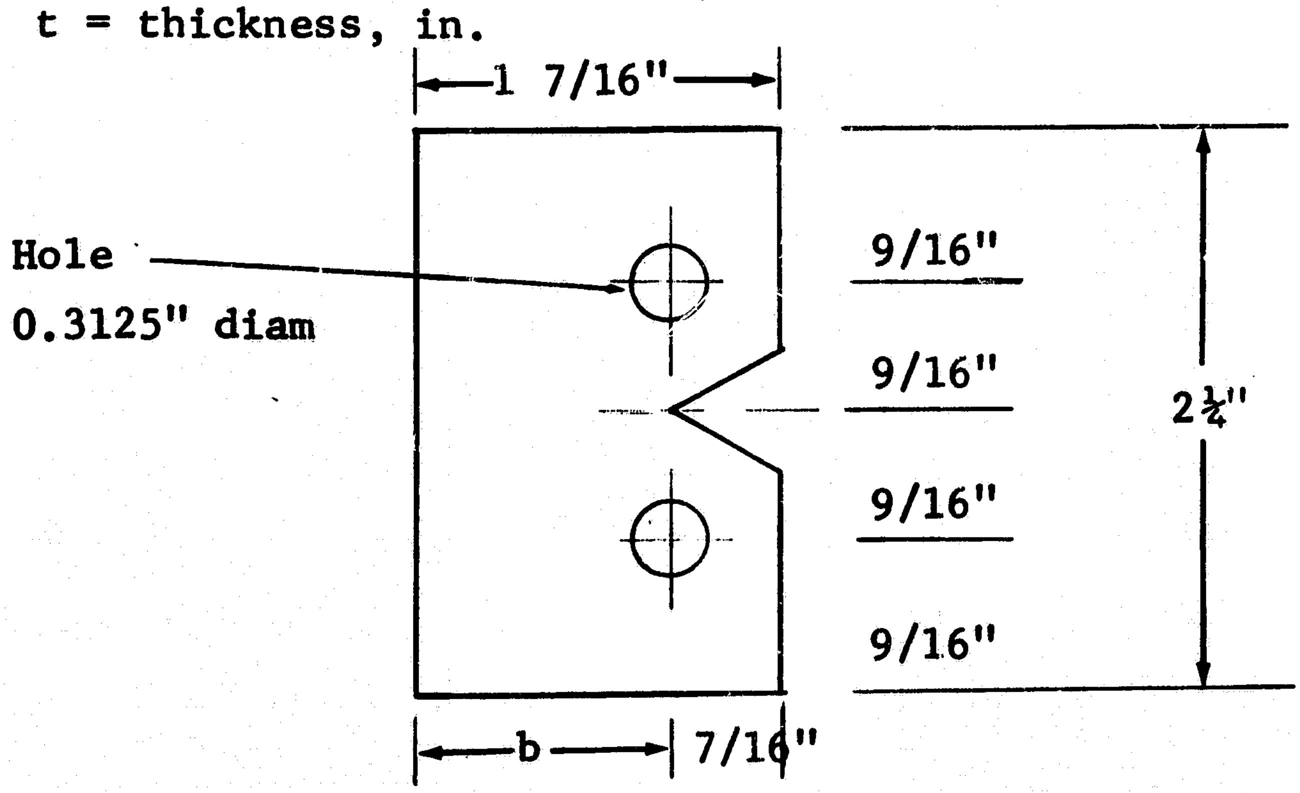
5.2 Tear Strength Data

One material, Aluminum 5086-H-34 (RTS-63), was evaluated in a Kahn-type tear test in which the sharp-notched specimens (Fig. 2-4 and sketch below) were loaded in the Instron tester until a crack developed at the root of the notch and traveled across the width of the specimen. The load/deformation curves provided the maximum load, from which the tear strength was computed, and the area under the curve, which is the energy required to initiate and propagate a crack.

The tear strength, S_t, was computed from (Ref. 2)

$$S_t = P/A + Mc/I = P/bt + 3P/bt = 4P/bt$$

where:
- P = maximum load, lb
- A = net area, in.^{2}, = bt
- M = moment, in.-lb
- c = distance from centroid to extreme fibers, in.
- I = moment of inertia, in.^{4}
- b = width at root of notch, in.
- t = thickness, in.



Tear Specimen

The measured values of t and P are tabulated in the data table; b was taken to be 0.995 in. for all specimens and other dimensions are shown in the sketch.

If the load/deformation curve is divided into two sections by a vertical line passing through the point of maximum load, the area under the first part of the curve is a measure of the energy necessary to initiate the crack and the area under the second part of the curve represents the energy necessary to propagate the crack across the specimen. Because of the length of the recorder traces, several feet in some instances, the two areas were obtained by a procedure in which three pairs of data points (x_{i-2}, y_{i-2}; x_{i-1}, y_{i-1}, x_i, y_i) from the Instron record were fitted to the function

$$y_i = Ax_i^2 + Bx_i + C$$

and integrated between the limits x_{i-2} and x_i. The first two points were then dropped and the next two points, x_{i+1} and x_{i+2}, were added to x_i and integrated between x_i and x_{i+2}, and so on. The summation of the integrals over the two sections of the Instron records gave the required data. Enough points were used to assure an accuracy in the area of at least $\pm 1.5\%$. The computations were made by use of the Hewlett-Packard 9100B desk calculator.

Table 5-17 presents the tear strength and area data for the aluminum alloy specimens, which were either unwelded (UW) or welded (W) or had a heat affected zone (HAZ). Table 5-18 gives the averages and standard deviations for each type specimen at each test condition. Table S-3 in the Summary gives the percent difference between data for the irradiated and control specimens and indicates if the difference is statistically significant at the 95% confidence level.

Table 5-17
TEAR STRENGTH DATA FOR ALUMINUM 5086-H-34 SHEET (UNWELDED, WELDED, AND HEAT AFFECTED ZONE) IRRADIATED AT 140°R AND TESTED AT SEVERAL TEMPERATURES
(Specification RTS 63)

Crosshead Speed = 0.050 in./min

Specimen No.	Type	Test Temp (°R)	Thickness (in.)	Max Load (lb)	Tear Strength (ksi)	Energy (in.-lb) To Initiate Crack	Energy (in.-lb) To Propagate Crack	Total Energy (in.-lb)	Unit Energy (in.-lb/in.^{2}) Propagation	Unit Energy (in.-lb/in.^{2}) Total	Neutron Fluence (n/cm^2) E >1.0 MeV	Neutron Fluence (n/cm^2) E <0.48 eV
328	UW	140	0.0647	1286	79.90	40.7	76.5	117.2	1188	1820	Control	
337	UW	140	0.0644	1280	79.90	42.0	85.9	128.0	1341	1997	Control	
353	UW	140	0.0649	1306	80.90	42.6	67.1	109.7	1039	1699	Control	
331	W	140	0.0639	860	54.15	24.0	63.5	87.5	1000	1378	Control	
345	W	140	0.0610	738	48.68	13.6	55.7	69.3	918	1143	Control	
348	W	140	0.0630	908	57.99	27.1	80.9	108.0	1292	1724	Control	
334	HAZ	140	0.0619	944	61.31	35.9	67.9	103.8	1103	1686	Control	
343	HAZ	140	0.0599	880	59.06	27.2	73.2	100.4	1228	1684	Control	
351	HAZ	140	0.0628	880	56.38	28.2	75.8	104.0	1214	1666	Control	
329	UW	140	0.0650	1466	90.74	35.4	52.5	87.8	812	1359	2.95(17)	1.8(16)
339	UW	140	0.0649	1460	90.44	34.7	50.5	85.2	782	1319	2.94(17)	1.8(16)
346	UW	140	0.0645	1450	90.94	36.2	50.0	86.2	779	1345	2.93(17)	1.8(16)
332	W	140	0.0614	1172	76.74	25.0	66.4	91.4	1087	1497	2.92(17)	1.8(16)
338	W	140	0.0593	1038	70.43	23.1	48.2	71.3	817	1209	2.90(17)	1.8(16)
354	W	140	0.0626	1236	79.37	27.2	65.6	92.8	1052	1490	2.91(17)	1.8(16)
335	HAZ	140	0.0615	1250	81.71	25.9	59.2	85.1	968	1391	2.89(17)	1.8(16)
341	HAZ	140	0.0615	1272	83.22	33.9	60.5	94.4	989	1544	2.88(17)	1.8(16)
350	HAZ	140	0.0625	1246	80.21	26.1	40.6	66.6	653	1072	2.87(17)	1.8(16)
355	UW	340	0.0644	1124	70.16	35.0	56.9	91.9	886	1434	Control	
367	UW	340	0.0646	1138	70.82	37.7	63.8	101.5	993	1579	Control	
381	UW	340	0.0648	1156	71.72	41.8	71.1	112.9	1102	1750	Control	
358	W	340	0.0622	638	41.27	23.2	53.8	77.0	871	1245	Control	
372	W	340	0.0617	786	51.21	34.4	72.9	107.2	1187	1747	Control	
374	W	340	0.0615	794	51.90	30.0	69.4	99.4	1134	1624	Control	
361	HAZ	340	0.0626	814	52.32	31.0	70.0	100.9	1124	1622	Control	
365	HAZ	340	0.0612	776	50.97	26.9	82.2	109.1	1349	1791	Control	
380	HAZ	340	0.0627	819	52.55	26.4	78.6	105.0	1260	1684	Control	

Table 5-17
TEAR STRENGTH DATA FOR ALUMINUM 5086-H-34 SHEET (UNWELDED, WELDED, AND HEAT AFFECTED ZONE) IRRADIATED AT 140°R AND TESTED AT SEVERAL TEMPERATURES (Cont'd)
(Specification RTS 63)

Specimen No.	Type	Test Temp (°R)	Thickness (in.)	Max Load (lb)	Tear Strength (ksi)	Energy (in.-lb) To Initiate Crack	Energy (in.-lb) To Propagate Crack	Total Energy (in.-lb)	Unit Energy (in.-lb/in.^{2}) Propagation	Unit Energy (in.-lb/in.^{2}) Total	Neutron Fluence (n/cm^2) E > 1.0 MeV	Neutron Fluence (n/cm^2) E < 0.48 eV
356	UW	340	0.0651	1178	72.74	38.9	67.4	106.3	1041	1641	2.86(17)	1.8(16)
366	UW	340	0.0648	off scale >1000 lb							2.85(17)	1.8(16)
373	UW	340	0.0649	1172	72.65	40.9	70.0	110.9	1084	1719	2.86(17)	1.8(16)
359	W	340	0.0618	791	51.50	21.9	59.0	80.9	960	1316	2.84(17)	1.8(16)
370	W	340	0.0641	854	53.60	28.2	51.3	79.5	805	1248	2.82(17)	1.8(16)
379	W	340	0.0619	913	59.29	37.1	79.4	116.5	1289	1891	2.83(17)	1.8(16)
362	HAZ	340	0.0638	922	58.10	30.3	92.9	123.2	1464	1941	2.81(17)	1.8(16)
376	HAZ	340	0.0613	859	56.38	28.8	95.1	123.9	1560	2032	2.79(17)	1.8(16)
377	HAZ	340	0.0630	880	56.15	25.3	90.0	115.3	1435	1839	2.80(17)	1.8(16)
357	UW	340	0.0644	1200	74.91	31.6	59.3	90.9	926	1419	2.00(18)	4.9(16)
360	W	340	0.0626	940	60.37	23.8	96.9	120.8	1556	1939	2.00(18)	4.9(16)
301	UW	540	0.0649	1060	65.66	26.6	47.8	74.4	741	1153	Control	
317	UW	540	0.0648	1080	67.00	29.5	43.4	72.9	673	1131	Control	
326	UW	540	0.0648	1072	66.56	31.1	30.6	61.7	475	957	Control	
401	UW	540	0.0644	1078	67.35	29.5	50.1	79.6	782	1243	Control	
304	W	540	0.0611	776	51.10	26.2	47.0	73.2	774	1206	Control	
319	W	540	0.0625	666	42.87	18.9	48.3	67.1	777	1081	Control	
327	W	540	0.0609	696	45.94	21.6	54.8	76.5	905	1262	Control	
402	W	540	0.0620	812	52.65	34.7	55.2	89.8	895	1457	Control	
307	HAZ	540	0.0634	812	51.49	28.0	80.4	108.4	1275	1719	Control	
311	HAZ	540	0.0623	796	51.34	24.4	59.9	84.3	967	1360	Control	
321	HAZ	540	0.0624	746	48.10	22.3	66.0	88.3	1064	1423	Control	
403	HAZ	540	0.0637	828	52.25	26.1	58.2	84.3	918	1329	Control	
302	UW	540	0.0653	1090	67.16	45.4	44.8	90.2	690	1390	2.78(17)	1.8(16)
314	UW	540	0.0649	1078	66.83	31.4	51.3	82.7	794	1281	2.76(17)	1.8(16)
325	UW	540	0.0654	1076	66.14	30.9	49.0	79.9	753	1228	2.77(17)	1.8(16)
404	UW	540	0.0649	1068	66.21	30.3	49.6	79.9	769	1238	2.69(17)	1.8(16)

Table 5-17

TEAR STRENGTH DATA FOR ALUMINUM 5086-H-34 SHEET (UNWELDED, WELDED, AND HEAT AFFECTED ZONE) IRRADIATED AT 140°R AND TESTED AT SEVERAL TEMPERATURES (Cont'd)

(Specification RTS 63)

Specimen No.	Type	Test Temp (°R)	Thickness (in.)	Max Load (lb)	Tear Strength (ksi)	Energy (in.-lb) To Initiate Crack	Energy (in.-lb) To Propagate Crack	Total Energy (in.-lb)	Unit Energy (in.-lb/in.^{2}) Propagation	Unit Energy (in.-lb/in.^{2}) Total	Neutron Fluence (n/cm^2) E >1.0 MeV	Neutron Fluence (n/cm^2) E < 0.48 eV
305	W	540	0.0623	788	50.85	21.3	69.5	90.8	1121	1464	2.75(17)	1.8(16)
310	W	540	0.0615	748	48.93	16.9	51.8	68.8	848	1125	2.73(17)	1.8(16)
318	W	540	0.0621	776	50.24	21.3	65.6	87.0	1062	1408	2.69(17)	1.8(16)
405	W	540	0.0624	820	52.83	19.7	43.1	62.8	694	1011	2.75(17)	1.8(16)
308	HAZ	540	0.0608	784	51.84	28.6	73.5	102.1	1215	1687	2.72(17)	1.8(16)
315	HAZ	540	0.0622	812	52.48	24.9	54.6	79.5	883	1285	2.70(17)	1.8(16)
322	HAZ	540	0.0606	804	53.34	22.1	73.2	95.3	1214	1581	2.71(17)	1.8(16)
406	HAZ	540	0.0603	756	50.44	22.3	51.9	74.2	866	1238	2.67(17)	1.8(16)

WANL Dwg. No. 100E445-H05, G06. Data to be used for material evaluation only. Do not use for design.

Table 5-18

AVERAGE, STANDARD DEVIATION, AND PERCENT STANDARD DEVIATION FOR TEAR STRENGTH DATA

Specimen Type	Control or Irrad	Test Temp (^{o}R)	Tear Strength			Energy to Initiate Crack			Energy to Propogate Crack		
			Ave (ksi)	Std Dev	% Std Dev	Ave (in.-lb)	Std Dev	% Std Dev	Ave (in.-lb)	Std Dev	% Std Dev
UW	Cont	140	80.23	0.58	0.72	41.77	0.97	2.33	76.50	9.40	12.29
UW	Irrad	140	90.71	0.25	0.28	35.43	0.75	2.12	51.00	1.32	2.59
UW	Cont	340	70.90	0.78	1.10	38.17	3.42	8.97	63.93	7.10	11.11
UW	Irrad	340	72.70	0.06	0.09	39.90	1.41	3.54	68.70	1.84	2.68
UW	Cont	540	66.64	0.73	1.10	29.18	1.88	6.43	42.98	8.71	20.26
UW	Irrad	540	66.59	0.49	0.74	34.50	7.28	21.10	48.68	2.76	5.67
W	Cont	140	53.61	4.68	8.73	21.57	7.07	32.79	66.70	12.90	19.34
W	Irrad	140	75.51	4.59	6.08	25.10	2.05	8.17	60.07	10.28	17.12
W	Cont	340	48.13	5.95	12.36	29.20	5.64	19.32	66.37	10.17	15.56
W	Irrad	340	54.80	4.03	7.36	29.07	7.64	26.27	63.23	14.52	22.96
W	Cont	540	48.14	4.54	9.42	25.35	6.92	27.31	51.33	4.28	8.34
W	Irrad	540	50.71	1.62	3.20	19.80	2.08	10.48	57.50	12.24	21.29
HAZ	Cont	140	58.92	2.47	4.19	30.43	4.76	15.64	72.30	4.03	5.57
HAZ	Irrad	140	81.71	1.51	1.84	28.63	4.56	15.93	53.43	11.13	20.84
HAZ	Cont	340	51.95	0.85	1.64	28.10	2.52	8.98	76.93	6.27	8.15
HAZ	Irrad	340	56.88	1.07	1.87	28.13	2.57	9.12	92.67	2.56	2.76
HAZ	Cont	540	50.80	1.84	3.62	25.20	2.43	9.64	66.13	10.09	15.26
HAZ	Irrad	540	52.03	1.22	2.35	19.80	2.08	10.48	63.30	11.66	18.42

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5.3 Fracture Toughness Data

Three types of precracked fracture toughness specimens were tested: compact tension, WOL (wedge open loading), and sheet. In addition, one material, ZrC, was in the form of small compact-tension-type specimens without precracks. The computational methods described below were used in obtaining the tabulated results.

5.3.1 Compact Tension Specimens

The fracture toughness data for the compact tension specimens presented in Tables 5-19 through 5-25 are in the following order:

M-7-1 Aluminum 6061-T6
RTS-61 Aluminum 6061-T61
M-21-2 Aluminum 7075-T73
M-16-2 18 Ni Maraging Steel
M-31-2 AISI 9310 Steel
M-38-3 ARMCO 22-13-5 Steel
RTS-67 ZrC (not precracked)

Data reduction for these materials was performed in accordance with the procedures recommended in the proposed ASTM Standard E399-70T (Ref. 3). This method covers the determination of the plane-strain fracture toughness characteristics of a notched and fatigue-cracked specimen. In this method, measurement of the plane-strain fracture toughness, K_{IC}, is based on the lowest load at which significant extension of the crack occurs. K_{IC} is determined from the load/displacement record, i.e., a graph

showing wedge opening vs Instron load, and the critical specimen dimensions shown in Figure 5-1. Referring to Figure 5-2, which illustrates the three types of load/displacement record that could result, K_{IC} is calculated as follows: the secant line, OP_S, is drawn through the origin with a slope 5% less than the slope of the tangent OA to the initial part of the record. The load at the intersection of the secant with the record is P_S. If the load at every point on the record which precedes P_S is lower than P_S, P_Q is equal to P_S (Fig. 5-2, Type I); if, however, there is a maximum load preceding P_S which exceeds it, then the maximum load is P_Q (Fig. 5-2, Types II and III). The conditional plane-strain fracture toughness, K_Q, is calculated from

$$K_Q = \frac{P_Q}{BW^{1/2}} \left[29.6\left(\frac{a}{W}\right)^{1/2} - 185.5\left(\frac{a}{W}\right)^{3/2} + 655.7\left(\frac{a}{W}\right)^{5/2} - 1017.0\left(\frac{a}{W}\right)^{7/2} + 638.9\left(\frac{a}{W}\right)^{9/2} \right] \tag{5-1}$$

where P_Q = maximum load, lb
B = thickness of specimen, in.
W = width of specimen, in.
a = average crack length, in., is the distance from precrack profile to the center of the holes where load is applied, i.e.,

$$a = \left(\frac{a_{1/4} + a_{1/2} + a_{3/4}}{3}\right) - \left(\frac{Z_2 - Y_2}{2}\right)$$

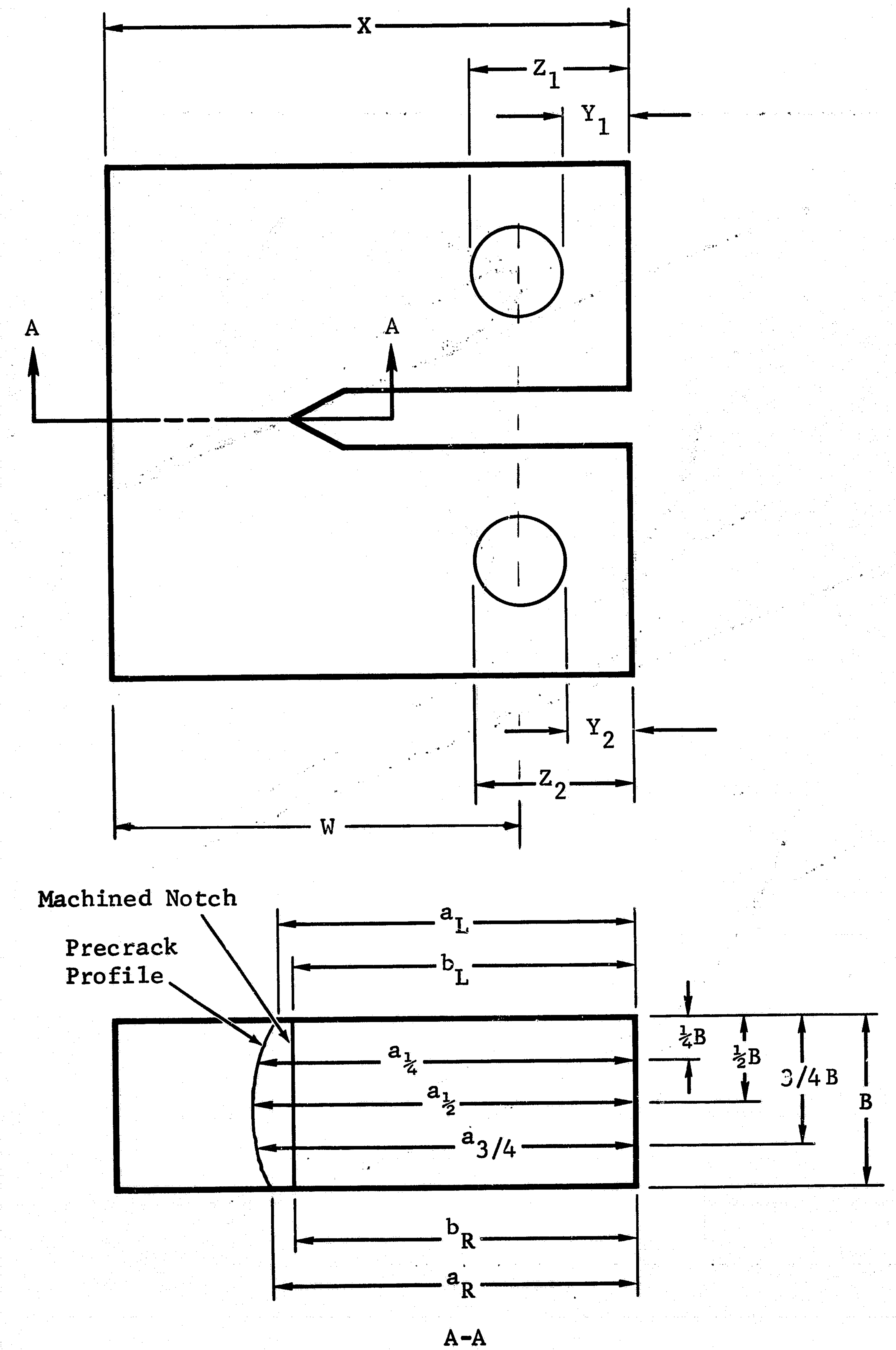


Figure 5-1 Measurements Required for Compact Tension Specimens

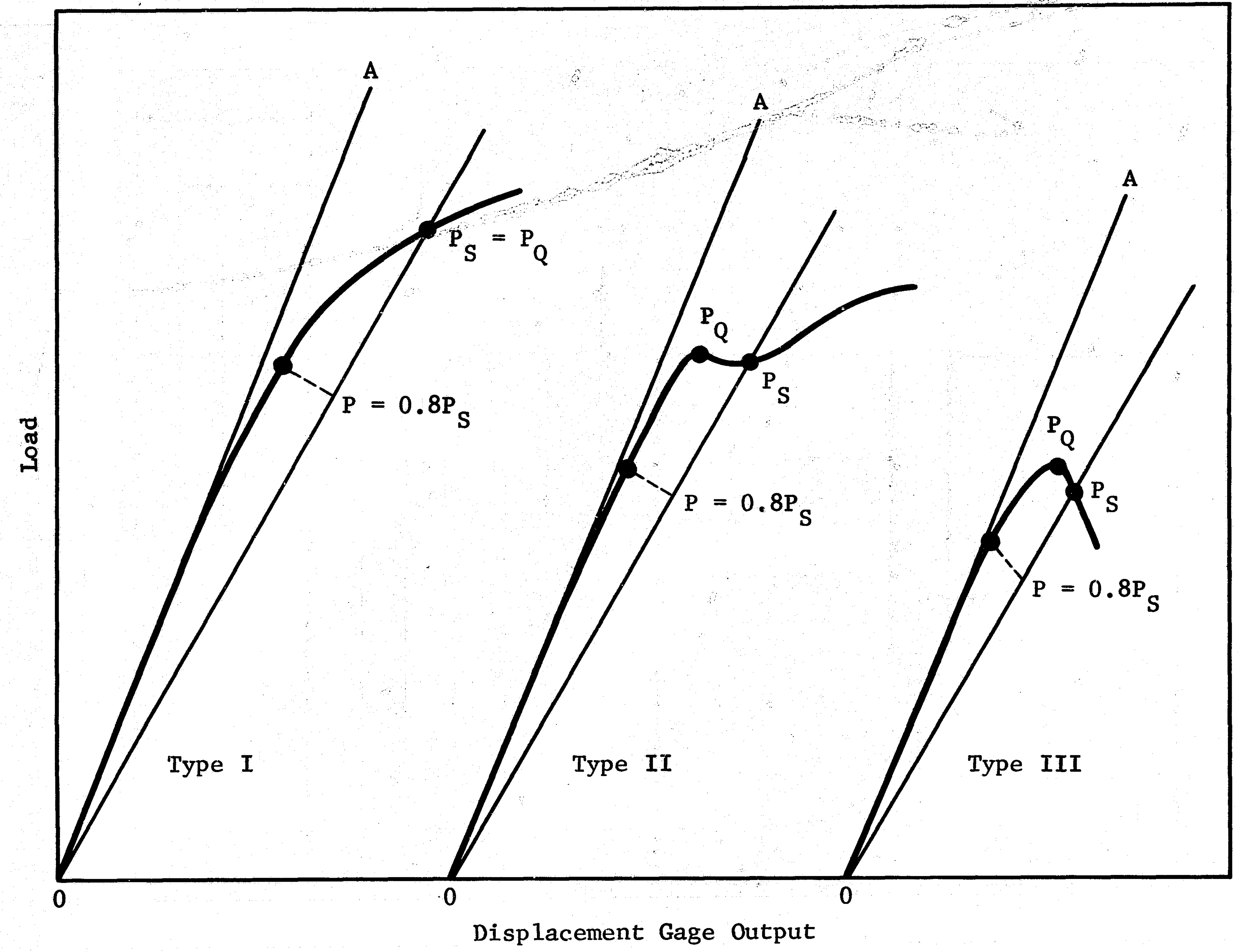


Figure 5-2 Principal Types of Load/Displacement Records

For the brittle ZrC specimens, which were not precracked, only the ultimate load could be obtained since they broke sharply. Equation 5-1 was used with P_U replacing P_Q and A, the average length of the machined notch, replacing a.

According to the proposed ASTM procedure (Ref. 3) the plane-strain fracture toughness K_{IC} is equal to the conditional value K_Q only if certain constraints are satisfied. In computing the K_Q values given in the data tables, the specimen precracks were also evaluated on the basis of the following criteria for <u>invalid</u> precracks:

1. Surface trace of fatigue crack is less than 0.05 in.
2. Internal trace of fatigue crack front is closer to the machined notched root than 0.05 in.
3. Difference between two crack length measurements exceeds 5% of the average.
4. Surface trace of fatigue crack is less than 90% of average crack length, a.

Table 5-27 contains a tabulation of those fracture toughness specimens which are invalid on the basis of one or more of the above criteria. The computed values for the criteria are given in order that it may be seen how much they are outside the specified limit. Specimens not listed in Table 5-27 are valid on the basis of the above four criteria.

Table S-2 of the summary contains the average conditional plain-strain fracture toughness (K_Q, KU_Q, or K_Q) for each group of specimens (including WOL and sheet). All the data were averaged without regard for invalid specimens. No statistical treatment has been performed because the validity of the specimens and perhaps other factors should be considered by anyone wishing to draw conclusions from this data.

To facilitate calculation of the fracture toughness characteristics, a computer program was prepared for the Hewlett-Packard Model 9100B desk calculator. All fracture toughness data reduction was accomplished in this manner.

5.3.2 WOL Specimens

The beryllium fracture toughness specimens (RTS-69) were of the WOL type (Fig. 2-2). The following equation, provided by WANL, was used to compute K_Q:

$$K_Q = \frac{P_Q}{Ba^{\frac{1}{2}}}\left[-5.605 + 61.27\left(\frac{a}{W}\right) - 141.08\left(\frac{a}{W}\right)^2 + 142.80\left(\frac{a}{W}\right)^3\right] \quad (5\text{-}2)$$

where the symbols are defined as previously. The data are given in Table 5-26. Specimens with invalid precracks based on the criteria given in Section 5.3.1 are listed in Table 5-27.

5.3.3 Sheet Specimens

Test specimens of the center-crack tension panel configuration were used for copper-boron (RTS-64 and RTS-65) and

Titanium 6Al 4V (M-9-3). The data reduction was performed in accordance with the WANL procedure summarized below.

Three fracture toughness stress intensity factors were computed from

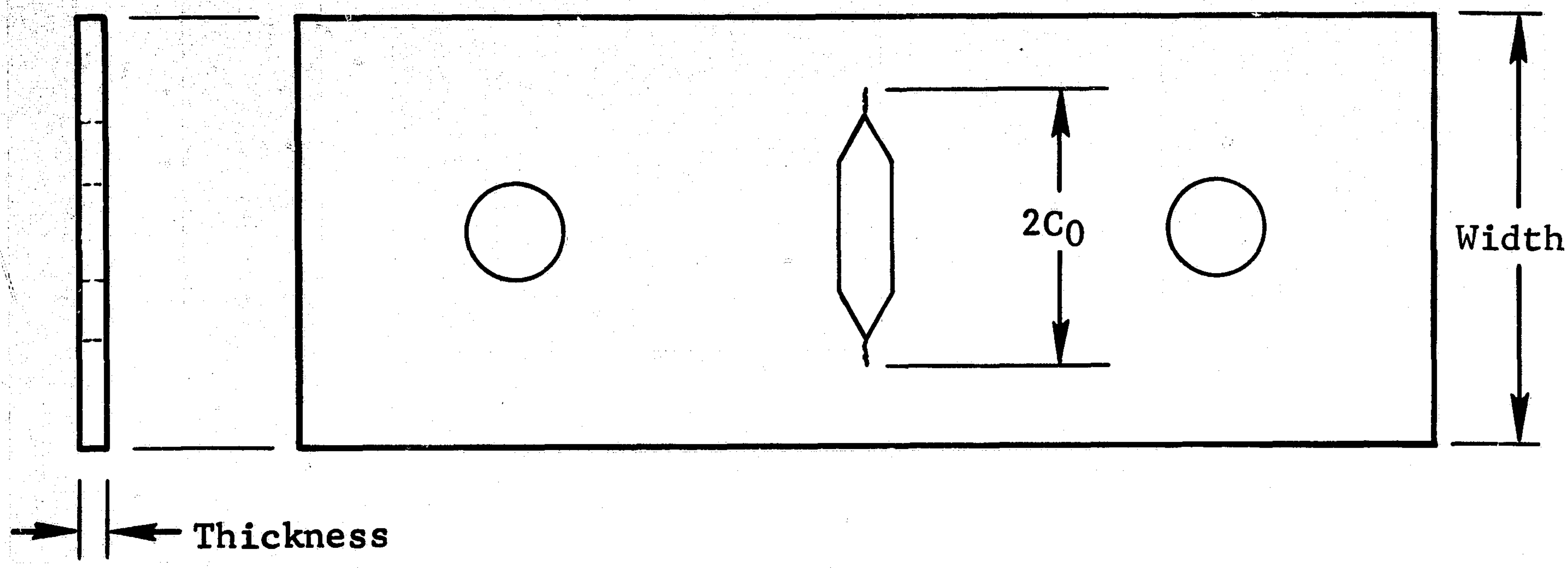
$$K_x = \frac{P_x\sqrt{A_x}}{BW}\left[1.77 + 0.227\left(\frac{2A_x}{W}\right) - 0.510\left(\frac{2A_x}{W}\right)^2 + 2.7\left(\frac{2A_x}{W}\right)^3\right] \qquad (5\text{-}3)$$

where K_x = stress intensity factor, ksi $\sqrt{\text{in.}}$
A_x = half-crack length, in.
B = specimen thickness, in.
W = specimen width, in.
P_x = load, lb

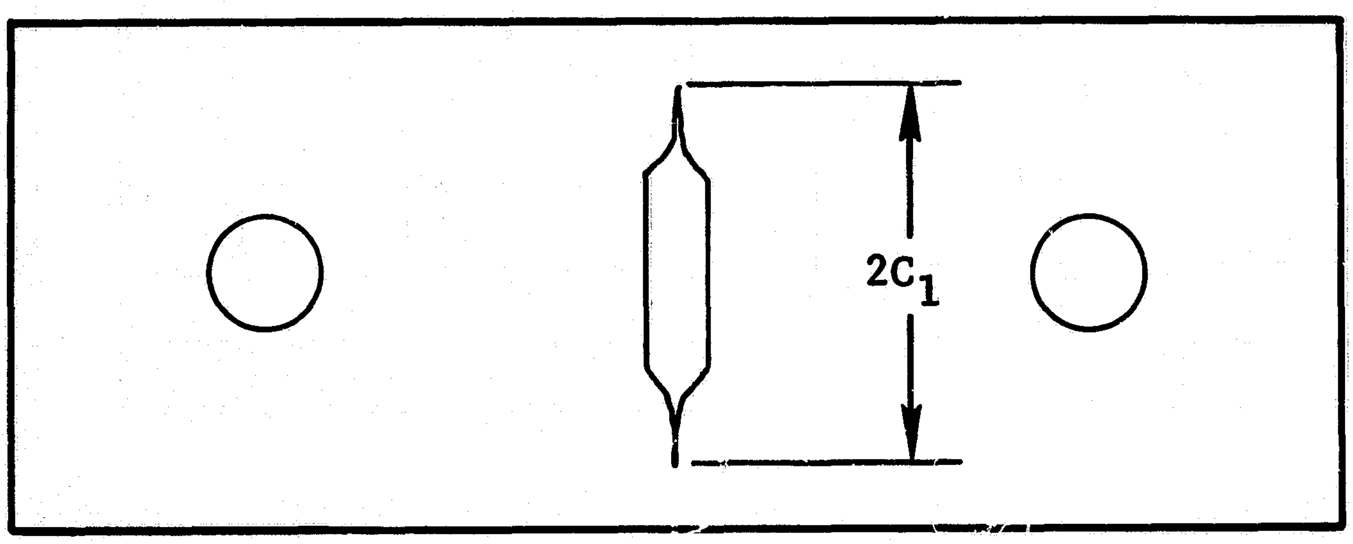
The crack length, which is illustrated in Figure 5-3, was measured both before ($2C_0$) and, if possible, after tensile testing ($2C_1$).

The stress intensity factor associated with the threshold, or onset, of slow, stable tear where the crack slowly extends after reaching a threshold stress level, K_0, is computed from Equation 5-3 using the initial crack length, $2C_0$, and the 5% offset load, P_0.

For those specimens which could be unloaded after having reached an ultimate load but before fracture (6 of 17 CuB specimens but no titanium specimens), the stress intensity factor associated with fracture, K_1, was calculated from Equation 5-3 using the ultimate load, P_U, and the crack width after testing, $2C_1$.



Measurements Made before Testing



Measurements Made after Testing

Figure 5-3 **Measurements Required for Center-Crack Fracture Toughness Specimens**

Since the initial portion of the load/deflection record was not linear for all specimens and hence the effects of radiation could not be effectively analyzed from K_0 data, and most specimens could not be unloaded before fracture, thus negating an analysis based upon K_1 data, an effective stress factor, K_{U0}, was computed for purposes of evaluating the effects of radiation. It was computed at ultimate load, P_U, using the initial crack length, $2C_0$.

Where applicable, gross and net section stress values were calculated from

$$\sigma_{gross} = \frac{P_U}{WB} \tag{5-4}$$

$$\sigma_{net} = \frac{P_U}{B(W-2C_1)} \tag{5-5}$$

where σ_{gross} is the maximum gross stress,
σ_{net} is the net section stress,

and other symbols are as previously defined.

Tables 5-28 and 5-29 give the data for the CuB and titanium, respectively.

Table 5-19

FRACTURE TOUGHNESS DATA FOR ALUMINUM 6061-T6 IRRADIATED AND TESTED AT 140°R
(Specification M-7-1)

Loading Rate = 6250 lb/min

Specimen Number	P_Q (lb)	K_Q (psi $\sqrt{\text{in.}}$)	P_U Ult Load (lb)	Radiation Exposure Neutron Fluence (n/cm^2) E >1 MeV	E < 0.48 eV	Machined Notch Left (in.)	Crack Length (in.) Edge Meas Left	1/4 B	1/2 B	3/4 B	Edge Meas Right	Machined Notch Right (in.)
Lot A												
345	4425	33682	5423	Control		0.8457	0.8927	1.0203	1.0737	1.0503	0.9432	0.8457
350	3720	29592	5415	Control		0.8524	0.9495	1.0560	1.1024	1.0665	0.9770	0.8393
351	3173	23935	5475	Control		0.8402	0.9334	1.0582	1.0657	1.0027	0.9487	0.8402
354	4718	34953	5025	5.8(16)	4.47(15)	0.7952	0.9193	1.0195	1.0446	1.0200	0.9336	0.7952
349	4725	34998	5010	6.6(16)	4.47(15)	0.8443	0.9370	1.0310	1.0394	1.0180	0.9278	0.8443
347	3675	28980	4665	7.1(16)	4.47(15)	0.8471	0.9547	1.0584	1.0779	1.0745	0.9685	0.8471
352	3518	26073	3518	3.58(18)	4.92(16)	0.8515	0.9431	1.0427	1.0330	1.0347	0.9869	0.8456
348	3375	24953	3660	3.75(18)	4.92(16)	0.8467	0.9381	1.0377	1.0252	1.0252	0.9008	0.8467
346	3420	27911	3420	3.90(18)	4.92(16)	0.8495	0.9386	1.0344	1.1490	1.0877	0.9713	0.8495
353	3000	22918	3000	3.90(18)	4.92(16)	0.8251	0.9698	1.0500	1.0485	1.0531	0.9570	0.8251
Lot B												
357	3990	29277	5085	Control		0.8431	0.9461	0.9994	1.0558	1.0056	0.9322	0.8432
361	3225	27435	4500	Control		0.8406	0.9814	1.1019	1.1289	1.1121	0.9485	0.8455
362	2880	24560	3420	Control		0.8466	0.9714	1.1129	1.1367	1.1006	0.9782	0.8466
355	4425	31026	4882	6.2(16)	4.47(15)	0.8426	0.8847	0.9731	1.0232	0.9829	0.9318	0.8426
364	3825	30171	4350	6.8(16)	4.47(15)	0.8463	0.9647	1.0631	1.0932	1.0502	0.9559	0.8567
359	4530	33329	5160	7.1(16)	4.47(15)	0.8493	0.9611	1.0266	1.0517	0.9991	0.9133	0.8493
360	3473	27471	3473	3.60(18)	4.92(16)	0.8483	0.9548	1.0511	1.0959	1.0623	0.9413	0.8483
358	3728	26671	3728	3.77(18)	4.92(16)	0.8438	0.9358	1.0112	1.0203	0.9798	0.9286	0.8438
363	4102	31138	4890	3.83(18)	4.92(16)	0.8448	0.9568	1.0355	1.0760	1.0257	0.9427	0.849[illegible]
356	3428	26342	3428	3.94(18)	4.92(16)	0.8486	0.9912	1.0656	1.0656	1.0315	0.9596	0.8486

ANSC Dwg. No. 1138365-07. Data to be used for material evaluation only. Do not use for design.

Table 5-20

FRACTURE TOUGHNESS DATA FOR ALUMINUM 6061-T61 (DM-320) IRRADIATED AT 140°R AND TESTED AT SEVERAL TEMPERATURES
(Specification RTS-61)

Loading Rate = 5000 lb/min

Specimen Number	Test Temp (°R)	P_Q (lb)	K_Q (psi $\sqrt{in.}$)	P_U Ult Load (lb)	Radiation Exposure Neutron Fluence (n/cm²) E >1 MeV	E < 0.48 eV	Machined Notch Left (in.)	Crack Length (in.) Edge Meas Left	1/4 B	1/2 B	3/4 B	Edge Meas Right	Machined Notch Right (in.)
109	140	3905	24606	4000	Control		0.8416	0.9829	0.9762	0.9222	0.9440	0.9828	0.8416
114	140	4225	28010	4225	Control		0.8392	0.9762	0.9802	0.9814	0.9852	0.9846	0.8392
116	140	3625	22933	3705	1.95(17)	5.8(15)	0.8423	0.9820	0.9457	0.9451	0.9523	0.9678	0.8423
111	140	4115	26706	4200	2.00(17)	5.8(15)	0.8404	0.9694	0.9480	0.9535	0.9991	0.9843	0.8404
134	140	3260	28931	3325	1.36(17)	5.8(15)	0.8261	1.1765	1.2025	1.1561	1.1157	1.0329	0.8261
110	140	3710	24885	3715	8.68(17)	3.4(16)	0.8452	0.9723	0.9802	0.9938	0.9966	1.0074	0.8452
113	140	3650	23360	3650	8.78(17)	3.4(16)	0.8271	1.0175	1.0179	0.9835	0.9699	0.9795	0.8271
112	140	3480	23229	3480	3.77(18)	4.0(16)	0.8396	0.9727	0.9812	0.9917	0.9878	1.0066	0.8396
115	140	3105	20994	3120	3.60(18)	4.0(16)	0.8349	1.0000	0.9912	1.0013	0.9909	0.9850	0.8349
136	140	5720	34281	5810	3.74(18)	4.0(16)	0.7971	0.9726	0.9149	0.9148	0.9032	0.9098	0.7971
125	273	3960	27072	4560	Control		0.8383	1.0143	1.0262	1.0098	0.9713	0.9960	0.8353
133	273	5400	33589	5650	Control		0.8404	0.9101	0.9020	0.9597	0.9540	0.9985	0.8365
127	273	3725	23821	3725	1.95(17)	5.8(15)	0.8429	1.0010	0.9809	0.9427	0.9527	0.9715	0.8426
130	273	5600	33238	5790	1.90(17)	5.8(15)	0.8420	0.9857	0.8995	0.8909	0.9164	0.9791	0.8494
128	273	3915	26649	3915	8.48(17)	3.4(16)							
129	273	3500	22825	3520	8.68(17)	3.4(16)	0.8399	0.9775	0.9707	0.9644	0.9809	0.9840	0.8410
126	273				3.93(18)	4.0(16)	0.8550	0.9440	1.0064	1.0064	0.9833	0.9839	0.8494
131	273	5400	33994	5450	4.05(18)	4.0(16)	0.8472	0.9653	0.9558	0.9353	0.9486	1.0190	0.8404
117	406	3390	23813	3440	Control		0.8508	0.9791	1.0184	1.0314	1.0110	0.9974	0.8450
123	406	4550	26820	5620	Control		0.8383	0.9755	0.8877	0.9047	0.9037	1.0143	0.8509
120	406	5400	33425	5700	1.71(17)	5.8(15)	0.8444	0.9796	0.9497	0.8976	0.9555	0.9843	0.8416
121	406	3700	25746	3935	1.81(17)	5.8(15)	0.8399	0.9791	1.0245	1.0208	0.9927	0.9764	0.8382
119	406	3180	20037	4390	8.00(17)	3.4(16)	0.8415	0.9829	0.9762	0.9222	0.9440	0.9828	0.8415
124	406	3980	26259	3980	7.42(17)	3.4(16)	0.8331	0.9747	0.9747	0.9767	0.9852	0.9817	0.8356
118	406	4500	30499	4525	4.13(18)	4.0(16)	0.8402	0.9670	0.9772	1.0022	1.0166	0.9897	0.8393
122	406	3600	23925	3600	4.10(18)	4.0(16)	0.8414	1.1034	1.0515	0.9614	0.9335	0.9581	0.8412
101	540	4210	28998	4215	Control		0.8389	0.9545	1.0015	1.0231	0.9985	0.9599	0.8389
107	540	4740	28652	5020	Control		0.7980	0.9668	0.9338	0.8757	0.9414	0.9530	0.7980

(cont'd)

WANL Dwg. No. 100E439H38. Data to be used for material evaluation only. Do not use for design.

Table 5-20(cont'd)

Specimen Number	Test Temp (°R)	P_Q (lb)	K_Q (psi $\sqrt{\text{in.}}$)	P_U Ult Load (lb)	Radiation Exposure Neutron Fluence (n/cm^2) $E > 1$ MeV	$E < 0.48$ eV	Machined Notch Left (in.)	Crack Length (in.) Edge Meas Left	1/4 B	1/2 B	3/4 B	Edge Meas Right	Machined Notch Right (in.)
104	540	5400	32147	5400	1.63(17)	5.8(15)	0.8294	0.9139	0.9189	0.9086	0.8882	0.9328	0.8294
105	540	4890	31177	5100	1.54(17)	5.8(15)	0.8407	0.9671	0.9211	0.9643	0.9829	1.0022	0.8407
102	540	5760	35293	5760	6.95(17)	3.4(16)	0.8310	0.9740	0.9553	0.9253	0.8999	0.9834	0.8310
106	540	5030	33822	5360	6.48(17)	3.4(16)	0.8296	0.9806	0.9976	0.9753	1.0045	0.9801	0.8296
135	540	5170	32090	5170	6.01(17)	3.4(16)	0.8316	0.9672	0.9420	0.9352	0.9314	0.9811	0.8316
108	540	4800	30638	5100	3.94(18)	4.0(16)	0.8091	0.9553	0.9682	0.9530	0.9434	0.9549	0.8091
103	540	4900	31406	5120	4.09(18)	4.0(16)	0.8259	0.9619	0.9783	0.9446	0.9508	0.9824	0.8259

Table 5-21

FRACTURE TOUGHNESS DATA FOR ALUMINUM 7075-T73 FORGING IRRADIATED AND TESTED AT 140°R
(Specification M-21-2)

Loading Rate = 6250 lb/min

Specimen Number	F_Q (lb)	K_Q (psi $\sqrt{\text{in.}}$)	P_U Ult Load (lb)	Radiation Exposure Neutron Fluence (n/cm²) E >1 MeV	E < 0.48 eV	Machined Notch Left (in.)	Crack Length (in.) Edge Meas Left	1/4 B	1/2 B	3/4 B	Edge Meas Right	Machined Notch Right (in.)
Lot A												
302	3728	26414	3795	Control		0.8446	0.9567	1.0368	1.0527	1.0068	0.9310	0.8446
307	3293	27741	3383	Control		0.8417	1.0925	1.1514	1.1548	1.0959	0.9429	0.8417
308	3983	28933	4013	Control		0.8465	0.9304	1.0267	1.0658	1.0483	0.9502	0.8465
388	4020	29601	4140	Control		0.8442	0.9078	1.0345	1.0759	1.0580	0.9959	0.8499
384	3960	27443	4035	2.62(16)	1.8(15)	0.8499	0.9252	1.0053	1.0370	1.0109	0.9409	0.8499
385	3840	28276	3900	2.79(16)	1.8(15)	0.8442	0.9078	1.0345	1.0759	1.0580	0.9959	0.8499
305	3698	26876	3848	2.87(16)	1.8(15)	0.8510	0.9282	1.0306	1.0718	1.0411	0.9581	0.8510
386	3840	26190	3893	2.97(16)	1.8(15)	0.8478	0.9572	1.0074	1.0238	0.9888	0.9219	0.8478
387	3600	24867	3713	3.35(17)	1.8(16)	0.8520	0.9330	1.0071	1.0346	1.0136	0.9559	0.8520
312	3840	27081	3840	3.65(17)	1.8(16)	0.8446	0.9239	1.0127	1.0462	1.0240	0.9562	0.8446
309	3503	25483	3540	4.01(17)	1.8(16)	0.8407	0.9309	1.0326	1.0707	1.0432	0.9495	0.8452
301	3660	26517	3660	4.23(17)	1.8(16)	0.8413	0.9684	1.0516	1.0614	1.0208	0.9145	0.8477
303*	3915	28037	3960	2.31(18)	4.9(16)	0.8521	0.9749	1.0341	1.0524	1.0239	0.9327	0.8521
310*	3915	27498	3960	2.74(18)	4.9(16)	0.8484	0.9551	1.0260	1.0413	1.0096	0.9166	0.8484
381*	4140	27965	4275	3.16(18)	4.9(16)	0.8443	0.8951	0.9726	1.0149	1.0106	0.9697	0.8478
Lot B												
338	3788	27406	3863	Control		0.8520	0.9937	1.0484	1.0660	1.0235	0.9126	0.8520
411	4140	27952	4140	Control		0.8482	0.8994	0.9671	1.0183	1.0185	0.9805	0.8482
415	3908	27283	3938	Control		0.8527	0.9246	1.0013	1.0402	1.0277	0.9649	0.8527
417	4035	28020	4043	Control		0.8441	0.9143	0.9848	1.0393	1.0389	0.9909	0.8536
335	4020	27875	4065	2.72(16)	1.8(15)	0.8490	0.9172	0.9786	1.0026	0.9772	0.9428	0.8527
344	3998	27659	3998	2.83(16)	1.8(15)	0.8523	0.9313	0.9927	1.0363	1.0238	0.9560	0.8523
341	3900	27085	3908	2.92(16)	1.8(15)	0.8501	0.9779	1.0195	1.0330	1.0121	0.9378	0.8501
336	3863	27073	3878	2.92(16)	1.8(15)	0.8467	0.9731	1.0343	1.0389	1.0071	0.9281	0.8467
339	3720	25269	3803	3.50(17)	1.8(16)	0.8430	0.9143	0.9825	1.0209	1.0103	0.9704	0.8485
414	3765	25590	3765	3.83(17)	1.8(16)	0.8488	0.9813	1.0083	1.0138	0.9962	0.9256	0.8488
413	3728	25884	3765	4.12(17)	1.8(16)	0.8433	0.9175	0.9908	1.0446	1.0265	0.9667	0.8433
412	3818	26521	3818	4.34(17)	1.8(16)	0.8524	0.9292	0.9915	1.0463	1.0233	0.9536	0.8524
333	3998	25168	3998	3.73(18)	4.9(16)	0.8055	0.8846	0.9495	0.9553	0.9482	0.9116	0.8055
416	4020	26699	4020	3.80(18)	4.9(16)	0.8435	0.9409	0.9871	1.0037	0.9821	0.9267	0.8519
343*	4133	26973	4185	2.53(18)	4.9(16)	0.8460	0.9061	0.9583	0.9961	0.9782	0.9312	0.8460

ANSC Dwg. No. 1138365-114. Data to be used for material evaluation only. Do not use for design.

*Annealed for 100 min at 540°R.

Table 5-22

FRACTURE TOUGHNESS DATA FOR 18 NI MARAGING STEEL IRRADIATED AND TESTED AT 140°R
(Specification M-16-2)

Loading Rate = 4000 lb/min

Specimen Number	P_Q (lb)	K_Q (psi $\sqrt{in.}$)	P_U Ult Load (lb)	Radiation Exposure: Neutron Fluence (n/cm^2) E >1 MeV	Radiation Exposure: Neutron Fluence (n/cm^2) E < 0.48 eV	Machined Notch Left (in.)	Crack Length (in.): Edge Meas Left	Crack Length (in.): 1/4 B	Crack Length (in.): 1/2 B	Crack Length (in.): 3/4 B	Crack Length (in.): Edge Meas Right	Machined Notch Right (in.)
Lot A												
29	5020	51444	5020	Control		0.6481	0.7232	0.7390	0.7370	0.7313	0.7028	0.6481
30	4820	49931	4820	|		0.6455	0.7293	0.7447	0.7410	0.7368	0.7146	0.6455
31	4525	46696	4525	|		0.6483	0.7063	0.7344	0.7403	0.7439	0.7285	0.6483
34	3560	36479	3560	|		0.6502	0.7100	0.7323	0.7355	0.7378	0.7245	0.6502
117	3790	38592	3790	Control		0.6408	0.7081	0.7314	0.7309	0.7288	0.7172	0.6408
122	4190	41924	4190	9.60(16)	4.47(15)	0.6437	0.7062	0.7139	0.7262	0.7269	0.7253	0.6437
36	4175	44682	4175	9.90(16)	4.47(15)	0.6517	0.7269	0.7451	0.7491	0.7485	0.7310	0.6517
118	4160	41667	4160	1.02(17)	4.47(15)	0.6449	0.7119	0.7155	0.7152	0.7253	0.7166	0.6449
116	3960	41362	3960	1.03(17)	4.47(15)	0.6563	0.7245	0.7412	0.7423	0.7397	0.7237	0.6468
37	4000	40412	4000	1.05(17)	4.47(15)	0.6447	0.7146	0.7253	0.7237	0.7222	0.7096	0.6447
127	4000	43384	4000	1.37(18)	3.58(16)	0.6607	0.7575	0.7662	0.7615	0.7516	0.7356	0.6607
38	4070	42525	4070	1.45(18)	3.58(16)	0.6521	0.7223	0.7340	0.7461	0.7554	0.7459	0.6521
119	3895	39627	3895	1.52(18)	3.58(16)	0.6492	0.7228	0.7299	0.7320	0.7332	0.7214	0.6492
124	3940	41078	3940	1.54(18)	3.58(16)	0.6520	0.7200	0.7356	0.7431	0.7515	0.7418	0.6520
28	4590	46704	4590	1.53(18)	3.58(16)	0.6464	0.7140	0.7292	0.7318	0.7328	0.7244	0.6464
Lot B												
265	3775	37589	3775	Control		0.6530	0.7088	0.7237	0.7219	0.7246	0.7128	0.6530
268	3790	36614	3790	|		0.6445	0.6947	0.7055	0.7060	0.7116	0.7029	0.6445
273	3565	36270	3565	|		0.6526	0.7236	0.7334	0.7349	0.7375	0.7261	0.6526
276	3090	31600	3110	|		0.6586	0.7215	0.7347	0.7379	0.7411	0.7331	0.6586
279	3650	36918	3650	Control		0.6498	0.7148	0.7260	0.7262	0.7237	0.7120	0.6498
252	3740	36517	3740	8.37(17)	4.47(15)	0.6470	0.7054	0.7125	0.7123	0.7153	0.7105	0.6470
271	3705	36661	3705	8.76(17)	4.47(15)	0.6486	0.7085	0.7173	0.7181	0.7258	0.7188	0.6486
274	3790	38646	3790	9.10(17)	4.47(15)	0.6450	0.7220	0.7323	0.7340	0.7362	0.7255	0.6450
253	3700	37879	3700	9.25(17)	4.47(15)	0.6521	0.7369	0.7435	0.7370	0.7345	0.7172	0.6521
257	3750	37373	3750	9.40(17)	4.47(15)	0.6509	0.7106	0.7229	0.7235	0.7248	0.7145	0.6509
260	3505	34872	3505	1.40(18)	4.47(16)	0.6510	0.7123	0.7234	0.7221	0.7231	0.7154	0.6510
269	3415	34153	3475	1.50(18)	4.47(16)	0.6514	0.7189	0.7268	0.7249	0.7265	0.7218	0.6514
270	3910	39128	3910	1.58(18)	4.47(16)	0.6534	0.7125	0.7272	0.7252	0.7256	0.7141	0.6534
255	3475	33541	3475	1.65(18)	4.47(16)	0.6489	0.7084	0.7085	0.7052	0.7082	0.7079	0.6489
254	3975	39579	3975	1.70(18)	4.47(16)	0.6459	0.7118	0.7236	0.7229	0.7229	0.7131	0.6459

ANSC Dwg. No. 1139208-118. Data to be used for material evaluation only. Do not use for design.

Table 5-23

FRACTURE TOUGHNESS DATA FOR SAE 9310 STEEL BAR IRRADIATED AND TESTED AT 140°R
(Specification M-31-2)

Loading Rate = 6250 lb/min

Specimen Number	P_Q (lb)	K_Q (psi $\sqrt{in.}$)	P_U Ult Load (lb)	Radiation Exposure Neutron Fluence (n/cm^2) E >1 MeV	E < 0.48 eV	Machined Notch Left (in.)	Crack Length (in.) Edge Meas Left	1/4 B	1/2 B	3/4 B	Edge Meas Right	Machined Notch Right (in.)
Lot A												
88	5190	37803	6075	Control		0.8292	0.9269	1.0484	1.0657	1.0338	0.9203	0.8381
89	4995	31926	6900	Control		0.8405	0.9046	0.9563	0.9637	0.9680	0.9322	0.8405
94	5880	37506	6810	Control		0.8472	0.9264	0.9670	0.9639	0.9467	0.9101	0.8472
428	7200	47372	7200	Control		0.8336	0.9364	0.9868	0.9854	0.9716	0.9351	0.8336
96	3900	24336	5490	2.3(16)	1.8(15)	0.8349	0.9248	0.9549	0.9458	0.9338	0.8919	0.8412
100	5535	36026	6570	2.3(16)	1.8(15)	0.8407	0.9200	0.9630	0.9769	0.9866	0.9519	0.8407
429	6465	40983	7380	2.3(16)	1.8(15)	0.8387	0.9439	0.9585	0.9589	0.9536	0.9375	0.8387
90	5415	33977	6750	2.4(16)	1.8(15)	0.8339	0.9393	0.9435	0.9540	0.9536	0.9235	0.8339
93	5100	32492	6495	2.4(16)	1.8(15)	0.8381	0.9148	0.9517	0.9600	0.9695	0.9432	0.8381
98	5925	38680	6495	2.6(17)	1.8(16)	0.8436	0.9482	0.9901	0.9794	0.9625	0.9310	0.8436
424	6750	42956	6750	2.6(17)	1.8(16)	0.8374	0.9216	0.9583	0.9625	0.9560	0.9232	0.8374
99	5655	36164	6705	3.1(17)	1.8(16)	0.8308	0.9130	0.9505	0.9651	0.9732	0.9521	0.8308
425	6660	41943	7200	4.0(17)	1.8(16)	0.8377	0.9105	0.9496	0.9540	0.9508	0.9348	0.8377
426	6255	40308	6750	4.2(17)	1.8(16)	0.8401	0.9313	0.9684	0.9684	0.9655	0.9479	0.8486
Lot B												
138	4410	27869	5625	Control		0.8343	0.9095	0.9424	0.9574	0.9595	0.9334	0.8406
439	5820	36160	6240	Control		0.8191	0.9016	0.9368	0.9463	0.9439	0.9133	0.8191
136	3255	20583	5220	Control		0.8368	0.9060	0.9448	0.9552	0.9592	0.9420	0.7957
135	3900	25359	5565	Control		0.8557	0.9403	0.9796	0.9773	0.9650	0.9409	0.8557
133	5085	32867	5925	2.4(16)	1.8(15)	0.8365	0.8883	0.9556	0.9731	0.9768	0.9491	0.8365
433	6360	41045	6360	2.3(16)	1.8(15)	0.8456	0.9378	0.9750	0.9707	0.9579	0.9211	0.8456
142	3300	20899	5100	2.3(16)	1.8(15)	0.8343	0.8942	0.9439	0.9588	0.9641	0.9352	0.8398
144	5475	34069	6825	2.3(16)	1.8(15)	0.8308	0.9044	0.9408	0.9489	0.9455	0.9246	0.8308
143	4500	27876	5100	2.3(16)	1.8(15)	0.8260	0.8957	0.9440	0.9449	0.9320	0.9001	0.8332
432	6000	36738	6000	3.1(17)	1.8(16)	0.8375	0.9018	0.9291	0.9308	0.9315	0.9121	0.8376
437	5580	34922	5910	2.7(17)	1.8(16)	0.8281	0.9141	0.9463	0.9488	0.9451	0.9243	0.8381
436	5685	37079	5745	2.6(17)	1.8(16)	0.8402	0.9437	0.9917	0.9788	0.9569	0.9347	0.8402
137	4230	26538	5400	4.1(17)	1.8(16)	0.8308	0.9230	0.9479	0.9560	0.9387	0.9267	0.8308
435	5385	35130	7140	4.3(17)	1.8(16)	0.8245	0.9671	0.9911	0.9770	0.9536	0.9263	0.8341

ANSC Dwg. No. 1138365-117. Data to be used for material evaluation only. Do not use for design.

Table 5-24

FRACTURE TOUGHNESS DATA FOR ARMCO 22-13-5 PLATE IRRADIATED AND TESTED AT 140°R
(Specification M-38-3)

Loading Rate = 6250 lb/min

Specimen Number	P_Q (lb)	K_Q (psi $\sqrt{in.}$)	P_U Ult Load (lb)	Radiation Exposure Neutron Fluence (n/cm^2) E > 1 MeV	E < 0.48 eV	Machined Notch Left (in.)	Crack Length (in.) Edge Meas Left	1/4 B	1/2 B	3/4 B	Edge Meas Right	Machined Notch Right (in.)
457	10905	85211	10905	Control		0.8410	0.9861	1.0838	1.0973	1.0887	1.0054	0.8410
459	9750	82461	10890			0.8499	1.0993	1.1686	1.0766	1.1646	0.0917	0.8499
462	11280	91620	11610			0.8555	1.0077	1.1039	1.1203	1.1164	1.0258	0.8555
467	11220	87775	11220			0.8461	1.0059	1.0906	1.0984	1.0854	1.0301	0.8461
468	10560	82476	10560	Control		0.8371	1.0056	1.0862	1.0950	1.0912	1.0016	0.8437
461	11250	88735	11250	1.20(17)	5.8(15)	0.8389	0.9890	1.0902	1.1003	1.0965	1.0290	0.8542
451	9900	79298	9900	1.28(17)	5.8(15)	0.8359	0.9989	1.1032	1.1119	1.1000	1.0224	0.8432
456	10785	82715	10785	1.38(17)	5.8(15)	0.8381	0.9790	1.0699	1.0833	1.0757	1.0007	0.8381
466	10350	80597	10350	1.45(17)	5.8(15)	0.8479	0.9918	1.0860	1.0941	1.0857	1.0014	0.8479
458	11370	91370	*	1.52(17)	5.8(15)	0.8465	1.0041	1.0984	1.1298	1.0935	0.9972	0.8465
465	8850	69237	8850	1.93(18)	4.5(16)	0.8444	0.9865	1.0843	1.0984	1.0926	1.0193	0.8444
455	8880	67003	8880	2.01(18)	4.5(16)	0.8247	0.9839	1.0612	1.0754	1.0729	0.9887	0.8247
454	8625	69209	8625	2.09(18)	4.5(16)	0.8444	1.0195	1.1086	1.1104	1.0985	1.0174	0.8444
453	7575	61547	8190	2.17(18)	4.5(16)	0.8395	0.9992	1.1030	1.1224	1.1149	1.0265	0.8395
464	8190	63498	8190	2.25(18)	4.5(16)	0.8341	0.9920	1.0770	1.0923	1.0886	1.0152	0.8341
452	8250	65607	8250	2.70(18)	4.9(16)	0.8357	1.0073	1.0949	1.1082	1.0994	1.0016	0.8357
463	8610	62665	8610	2.90(18)	4.9(16)	0.8061	0.9524	1.0389	1.0475	1.0434	0.9693	0.8182
469	7500	58899	7500	3.10(18)	4.9(16)	0.8328	0.9887	1.0851	1.0975	1.0943	1.0021	0.8382
470	8400	66609	8400	3.26(18)	4.9(16)	0.8508	1.0021	1.0981	1.1037	1.0963	1.0028	0.8508
460	8190	62378	8190	3.40(18)	4.9(16)	0.8266	0.9892	1.0733	1.0808	1.0708	0.9929	0.8266

* Displacement gage came out.

ANSC Dwg. No. 1138365-15. Data to be used for material evaluation only. Do not use for design.

Table 5-25

FRACTURE TOUGHNESS DATA FOR ZrC PLATE IRRADIATED AT 140°R AND TESTED AT 140°R AND 540°R

(Specification RTS-67)

Loading Rate = 60 lb/min

Specimen No.	Test Temp (°R)	B Specimen Thickness (in.)	W Specimen Width (in.)	Ave Machine Notch (in.)	P_u Ult Load (lb)	K_u [a] (psi$\sqrt{\text{in.}}$)	Neutron Fluence (n/cm^2) E > 1 MeV	E < 0.48 eV
520	140	0.2492	0.4949	0.2281	9.03	442.5	Control	
501	540	0.2482	0.4975	0.2285	7.80	381.1	Control	
507	540	0.2485	0.4962	0.2285	7.35	360.4	Control	
519	140	0.2490	0.4978	0.2286	8.85	430.7	2.63(18)	4.0(16)
516	140	0.2488	0.4962	0.2292	6.18	303.9	2.82(18)	4.0(16)
515	140	0.2486	0.4984	0.2293	4.05	197.8	2.89(18)	4.0(16)
509	540	0.2490	0.4956	0.2287	7.26	356.4	2.35(18)	4.0(16)
508	540	0.2489	0.4975	0.2278	7.95	385.8	2.41(18)	4.0(16)
506	540	0.2487	0.4970	0.2274	8.25	400.6	2.48(18)	4.0(16)
502	540	0.2485	0.4970	0.2276	8.88	431.9	2.61(18)	4.0(16)

[a] toughness calculated on basis of ultimate load.

WANL Dwg. No. 577F544H14F. Data to be used for material evaluation only. Do not use for design.

Table 5-26

FRACTURE TOUGHNESS DATA FOR BERYLLIUM IRRADIATED AT 140°R AND TESTED AT 140° and 540°R
(Specification RTS-69)

Loading Rate = 400 lb/min

Specimen Number	Test Temp (°R)	P_Q (lb)	K_Q (psi $\sqrt{in.}$)	P_U Ult Load (lb)	Radiation Exposure Neutron Fluence (n/cm²) E >1 MeV	E < 0.48 eV	Machined Notch Left (in.)	Crack Length (in.) Edge Meas Left	1/4 B	1/2 B	3/4 B	Edge Meas Right	Machined Notch Right (in.)
14	140	2060	10540	2060	Control		0.8649	0.9230	0.9382	0.9447	0.9427	0.9294	0.8649
27	140	1804	9118	1804	Control		0.8599	0.9141	0.9288	0.9240	0.9202	0.9318	0.8599
25	140	1344	6875	1344	3.22(18)	4.0(16)	0.8700	0.9235	0.9440	0.9413	0.9404	0.9318	0.8700
26	140	1072	5385	1072	3.25(18)	4.0(16)	0.8613	0.9023	0.9077	0.9116	0.9133	0.9245	0.8613
24	540	1920	9790	1920	Control		0.8724	0.9250	0.9361	0.9414	0.9342	0.9215	0.8724
30	540	2560	12880	2560	Control		0.8709	0.9193	0.9171	0.9164	0.9186	0.9177	0.8709
29	540	2390	11936	2390	3.00(18)	4.0(16)	0.8731	0.9054	0.9092	0.9058	0.9059	0.9112	0.8731

WANL Dwg. No. 100E439 H18. Data to be used for material evaluation only. Do not use for design.

Table 5-27

INVALID FRACTURE TOUGHNESS SPECIMENS BASED ON FOUR FATIGUE CRACK CRITERIA

Material	Specimen No.	1 Surface Trace (in.)	2 Internal Trace (in.)	3 Trace Difference (%)	4 Surface Trace (%)
Al 6061-T6	345	0.047	-	5.1	85.2
	350	-	-	-	88.3
	351	-	-	6.0	89.6
	354	-	-	-	89.4
	347	-	-	-	89.2
	348	-	-	-	87.5
	346	-	-	10.5	86.1
	357	-	-	5.5	-
	361	-	-	-	85.1
	362	-	-	-	87.0
	355	0.042	-	-	89.0
	364	-	-	-	89.4
	359	-	-	5.1	89.0
	360	-	-	-	88.0
Al 6061-T61	109	-	-	5.7	-
	111	-	-	5.3	-
	134	-	-	7.5	89.2
	125	-	-	5.5	-
	133	-	-	6.2	-

Criteria:
1. Surface trace of fatigue crack is less than 0.05 in.
2. Internal trace of fatigue crack front is closer to the machined notched root than 0.05 in.
3. Difference between two crack length measurements exceeds 5 percent of the average.
4. Surface trace of crack is less than 90% of average crack length, a.

Table 5-27 (cont'd)

Material	Specimen No.	1 Surface Trace (in.)	2 Internal Trace (in.)	3 Trace Difference (%)	4 Surface Trace (%)
	130	-	0.045	-	-
	123	-	0.046	-	-
	120	-	-	6.2	-
	119	-	-	5.7	-
	122	-	-	12.0	-
	107	-	-	7.2	-
	105	-	-	6.5	-
	102	-	-	6.0	-
Al 7075-T73	307	-	-	5.7	83.1
	308	-	-	-	88.9
	388	-	-	-	86.0
	385	-	-	-	86.0
	305	-	-	-	88.6
	309	-	-	-	88.8
	301	-	-	-	87.6
	310	-	-	-	89.4
	381	-	-	-	89.6
	338	-	-	-	87.2
	411	-	-	5.1	89.8
	417	-	-	5.3	89.6
	413	-	-	5.3	89.9
	412	-	-	5.4	-
18 Ni Maraging Steel		No invalid specimens			
SAE 9310 Steel	88	-	-	-	87.7

Table 5-27 (cont'd)

Material	Specimen No.	1 Surface Trace (in.)	2 Internal Trace (in.)	3 Trace Difference (%)	4 Surface Trace (%)
ARMCO 22-13-5	453	-	-	-	89.7
ZrC	Specimens not precracked				
Beryllium	24	0.049	-	-	-
	30	0.047	0.046	-	-
	29	0.032	0.033	-	-
	26	0.041	0.046	-	-

Table 5-28

FRACTURE TOUGHNESS DATA FOR Cu B^{10} (18%) (DM-180) and Cu B^{N} (18%) (DM-198) SHEET IRRADIATED AT 140°R AND TESTED AT 140° and 540°R
(Specifications RTS-64 and RTS-65)

Crosshead Speed = 0.020 in./min

Specimen No.	Material	Test Temp (°R)	B Thickness (in.)	W Width (in.)	$2C_0$ Initial Crack (in.)	$2C_1$ Final Crack (in.)	P_O, 5% Offset Load (lb)	P_U Ult Load (lb)	5% Offset Stress (ksi)	Max Gross Stress (ksi)	Net Section Stress (ksi)	K_O (ksi $\sqrt{in.}$)	K_1 (ksi $\sqrt{in.}$)	K_{UO}[a] (ksi $\sqrt{in.}$)	Neutron Fluence (n/cm²) E > 1 MeV	Neutron Fluence (n/cm²) E < 0.48 eV
2	Cu B^{10}	140	0.0992	3.3493	1.1434	1.7777	1800	3565	5.42	10.73	22.87	7.76	21.75	15.38	Control	
12	Cu B^{10}	540	0.0990	3.3171	1.0818	1.7491	1655	2715	5.04	8.27	17.49	6.98	16.57	11.45	Control	
9	Cu B^{10}	140	0.0998	3.1883	0.9574	b	4540	6430	14.27	20.21	-	18.41	-	26.08	2.27(18)	4.9(16)
6	Cu B^{10}	140	0.0988	3.2773	1.1048	b	4600	6310	14.21	19.49	-	19.98	-	27.40	2.29(18)	4.9(16)
20	Cu B^{10}	540	0.0993	3.2917	1.1332	b	3350	4200	10.25	12.85	-	14.64	-	18.36	2.19(18)	4.9(16)
19	Cu B^{10}	540	0.0991	3.2098	1.1835	b	3350	4085	10.53	12.84	-	15.55	-	18.96	2.22(18)	4.9(16)
16	Cu B^{10}	540	0.0993	3.2781	1.0550	b	2950	4235	9.06	13.01	-	12.38	-	17.77	2.25(18)	4.9(16)
1	Cu B^{N}	140	0.0579	3.0700	1.3747	1.7497	650	1414	3.66	7.95	18.50	6.10	16.62	13.27	Control	
3	Cu B^{N}	140	0.0582	3.0883	1.5397	1.8619	730	1400	4.06	7.79	19.61	7.45	17.38	14.29	Control	
11	Cu B^{N}	540	0.0588	3.0261	1.4565	1.7401	644	1202	3.62	6.76	15.90	6.37	14.15	11.89	Control	
13	Cu B^{N}	540	0.0579	3.1014	1.4423	b	564	1272	3.14	7.08	-	5.43	-	12.25	Control	
14	Cu B^{N}	540	0.0579	3.0737	1.4488	1.6333	612	1118	3.44	6.28	13.41	5.99	12.22	10.94	Control	
31	Cu B^{N}	140	0.0587	3.0500	1.4653	b	1840	2765	10.28	15.44	-	18.13	-	27.24	2.37(18)	4.9(16)
5	Cu B^{N}	140	0.0587	3.1180	1.3947	b	1600	2510	8.74	13.71	-	14.68	-	23.03	2.39(18)	4.9(16)
18	Cu B^{N}	540	0.0590	3.0757	1.4088	b	1560	2042	8.60	11.25	-	14.62	-	19.14	2.31(18)	4.9(16)
17	Cu B^{N}	540	0.0585	3.0061	1.4543	b	1526	1604	8.68	9.12	-	15.29	-	16.07	2.33(18)	4.9(16)
15	Cu B^{N}	540	0.0588	3.0941	1.3950	b	1830	2190	10.06	12.04	-	16.94	-	20.27	2.35(18)	4.9(16)

WANL Dwg No. 577F686H03 and 577F686H04. Data to be used for material evaluation only. Do not use for design.

[a] K_{UO} is calculated at ultimate load using initial crack length.

[b] Specimen broke at ultimate load; no measurement of final crack length was possible.

Table 5-29

FRACTURE TOUGHNESS DATA FOR TITANIUM 6Al 4V WELDED SHEET IRRADIATED AND TESTED AT 140°R
(Specification M-9-3)

Loading Rate = 23,000 lb/min

Specimen No.	B Thickness (in.)	W Width (in.)	$2C_0$ Initial Crack (in.)	$2C_1$ Final Crack (in.)	P_U Ultimate Load (lb)	Ultimate Stress (ksi)	K_{U_0}[a] (ksi $\sqrt{in.}$)	Neutron Fluence n/cm² E >1 MeV	Neutron Fluence n/cm² E < 0.48 eV
7	0.2021	3.0065	1.1020	b	26300	43.28	61.61	Control	
9	0.2043	3.0076	1.1185		28000	45.57	65.52	Control	
13	0.2056	3.0068	1.1399		28000	45.29	65.99	Control	
16	0.2046	3.0068	1.1357		26200	42.59	61.89	Control	
18	0.2035	3.0059	1.0858		27400	44.79	63.13	3.16(16)	1.8(15)
10	0.2062	3.0074	1.0283		27600	44.51	60.51	3.21(16)	1.8(15)
12	0.2021	3.0071	1.0437		27000	44.43	60.99	3.25(16)	1.8(15)
15	0.2066	3.0078	1.0955		27600	44.42	62.96	3.28(16)	1.8(15)
20	0.2003	3.0058	1.0811		26100	43.35	60.92	3.33(16)	1.8(15)
21	0.2035	3.0078	1.0634		23200	37.90	52.67	5.60(17)	1.8(16)
11	0.2049	3.0072	1.0998		23640	38.37	54.54	5.66(17)	1.8(16)
17	0.2062	3.0092	1.0555		22250	35.86	49.58	5.70(17)	1.8(16)
14	0.2036	3.0074	1.0883		23600	38.54	54.40	5.75(17)	1.8(16)
8	0.2043	3.0055	1.0618		23000	37.46	52.01	5.81(17)	1.8(16)

ANSC Dwg No. 1138226-2909. Data to be used for material evaluation only. Do not use for design.

[a]K_{U_0} is calculated at ultimate load using initial crack length.

[b]All specimens broke at the ultimate load; no measurement of final crack length was possible.

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5.4 Flexure Data

The ZrC flexure specimens (RTS-66) were tested by an ASTM procedure (Ref. 1) which actually applies to plastics. However, data provided by WANL for a control specimen indicated that Equation 3 of ASTM D790 was used. This equation gives the maximum fiber stress in a simple beam supported at two points and loaded at the midpoint:

$$S = 3PL/2bd^2 \qquad (5\text{-}6)$$

where S = stress in the outer fiber at midspan, psi
P = maximum load, lb
L = span, in. (= 1 in.)
b = width of beam, in.
d = depth (thickness) of beam, in.

Table 5-30 gives the results of the measurements and computations using Equation 5-6. The table also includes a "Chart Deflection" which is the specimen deflection at rupture as determined from chart travel with the Instron operating at a constant crosshead speed. Table S-3 of the Summary gives the percent differences between data for irradiated and control specimens.

Table 5-30
FLEXURE DATA FOR ZrC PLATE IRRADIATED AT 140°R AND TESTED AT 140°R AND 540°R
(Specification RTS-66)

Crosshead Speed = 0.005 in./min

Specimen No.	Test Temp (°R)	Width (in.)	Thickness (in.)	Chart Deflection (in.)	Max Load (lb)	Max Fiber Stress (ksi)	Neutron Fluence (n/cm^2) E >1 MeV	Neutron Fluence (n/cm^2) E < 0.48 eV
611	140	0.2487	0.1993	0.0099	12.0	1.82	Control	
614	140	0.2491	0.1992	0.0120	11.4	1.73	Control	
616	140	0.2475	0.1976	0.0162	12.5	1.95	Control	
617	140	0.2491	0.1992	0.0159	13.6	2.06	Control	
620	140	0.2489	0.1993	0.0100	12.4	1.88	Control	
Ave				0.0128	12.4	1.89		
Std Dev				0.0031	0.8	0.13		
% Std Dev				24.1	6.5	6.7		
615	140	0.2480	0.1989	0.0105	12.4	1.89	2.84 (18)	4.0 (16)
618	140	0.2500	0.1994	0.0102	13.8	2.08	2.84 (18)	4.0 (16)
619	140	0.2482	0.1983	0.0180	13.5	2.07	2.84 (18)	4.0 (16)
Ave				0.0129	13.2	2.01		
Std Dev				0.0044	0.7	0.11		
% Std Dev				34.3	5.6	5.3		
601	540	0.2491	0.1995	0.0088	13.9	2.10	Control	
602	540	0.2485	0.1986	0.0073	11.2	1.72	Control	
607	540	0.2497	0.1994	0.0100	10.4	1.58	Control	
610	540	0.2495	0.1990	0.0080	13.8	2.10	Control	
Ave				0.0085	12.3	1.88		
Std Dev				0.0012	1.8	0.27		
% Std Dev				13.6	14.5	14.2		
603	540	0.2496	0.1989	0.0180	12.9	1.96	2.84 (18)	4.0 (16)
605	540	0.2486	0.1981	0.0085*	4.3*	0.66*	2.84 (18)	4.0 (16)

Table 5-30
FLEXURE DATA FOR ZrC PLATE IRRADIATED AT 140°R AND TESTED AT 140°R AND 540°R (Cont'd)
(Specification RTS-66)

Specimen No.	Test Temp (°R)	Width (in.)	Thickness (in.)	Chart Deflection (in.)	Max Load (lb)	Max Fiber Stress (ksi)	Neutron Fluence (n/cm^2) E >1 MeV	E < 0.48 eV
606	540	0.2495	0.1982	0.0070	11.0	1.68	2.84 (18)	4.0 (16)
608	540	0.2488	0.1992	0.0107	10.6	1.60	2.84 (18)	4.0 (16)
609	540	0.2491	0.1993	0.0066	11.2	1.70	2.84 (18)	4.0 (16)
Ave				0.0106	11.4	1.74		
Std Dev				0.0053	1.0	0.16		
% Std Dev				50.0	8.9	9.0		

* Not included in average

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5.5 Data for Springs

Beryllium-copper Belleville springs (M-39-1) and A-286 coil springs (Fig. 2-5) (RTS-58) were tested in compression. The load required to compress the Belleville springs to a height of 0.081 in. is tabulated in Table 5-31. The heights at loads of 50, 100, and 150 lb taken from the Instron record are also tabulated in Table 5-31. While there is an observed difference between the pre- and post-irradiation measurements, a comparison of data for the uncompressed control springs indicates a bias between the measurements taken before the irradiation and those taken following the irradiation. Although the source of this discrepancy could not be determined, the assumption of a bias results in the conclusion that there is no statistically significant difference between the pre- and post-irradiation data for the irradiated springs.

The A-286 springs were compressed at a constant rate to a length slightly less than 2.754 in. The spring constants at lengths of 3.292 and 2.754 in. were then determined from the load/deflection records. The data are in Table 5-32. Again an apparent bias combined with the variability in the data leads to the conclusion that there is no statistically significant difference between the pre- and post-irradiation measurements.

Table 5-31

LOAD DEFLECTION OF BERYLLIUM-COPPER BELLEVILLE SPRINGS IRRADIATED AT 140°R
(Specification M-39-1)

Crosshead Speed = 0.050 in./min

Spring No.	Neutron Fluence (n/cm^2) E >1 MeV	E < 0.48 eV	Height at 540°R (in.)	Test Temp.	Load (lb) at 0.081 in. Height Pre	Post	Height (in.) at Given Load (lb) Pre 50	Pre 100	Pre 150	Post 50	Post 100	Post 150
			Springs compressed to 0.08 in. during irradiation.									
11	Control[a]		0.152	540	178	165	0.130	0.114	0.097	0.132	0.114	0.091
3	Control		0.163	540	180	165	0.129	0.114	0.097	0.131	0.114	0.091
6	Control		0.149	540	192	177	0.130	0.115	0.100	0.132	0.116	0.096
11	Control			140	170	175	0.126	0.112	0.091	0.130	0.116	0.094
3	Control			140	175	172	0.125	0.110	0.093	0.127	0.114	0.092
6	Control			140	192	172	0.133	0.118	0.101	0.129	0.116	0.094
12	7.39(17)	1.80(16)	0.160	540	176	160	0.129	0.113	0.096	0.131	0.111	0.088
9	7.39(17)	1.80(16)	0.152	540	178	168	0.131	0.115	0.099	0.131	0.114	0.093
7	7.39(17)	1.80(16)	0.150	540	179	168	0.131	0.115	0.098	0.132	0.115	0.093
12	7.39(17)	1.80(16)		140	173	169	0.128	0.113	0.093	0.126	0.111	0.087
9	7.39(17)	1.80(16)		140	175	154	0.128	0.112	0.092	0.128	0.112	0.083
7	7.39(17)	1.80(16)		140	173	170	0.129	0.113	0.091	0.132	0.117	0.095
			Springs compressed to 0.07 in. during irradiation.									
5	Control[a]		0.153	540	178	177	0.130	0.115	0.098	0.133	0.117	0.095
8	Control		0.148	540	172	168	0.128	0.113	0.096	0.130	0.114	0.092
10	Control		0.150	540	172	159	0.128	0.113	0.096	0.130	0.112	0.088
5	Control			140	183	182	0.130	0.116	0.097	0.130	0.116	0.095
8	Control			140	178	168	0.129	0.115	0.096	0.129	0.115	0.091
10	Control			140	170	168	0.127	0.113	0.093	0.129	0.114	0.091
2	7.39(17)	1.80(16)	0.151	540	183	185	0.131	0.116	0.101	0.136	0.121	0.103
1	7.39(17)	1.80(16)	0.154	540	169	169	0.127	0.111	0.093	0.135	0.116	0.092
4	7.39(17)	1.80(16)	0.151	540	182	185	0.130	0.115	0.100	0.134	0.119	0.101
2	7.39(17)	1.80(16)		140	185	173	0.130	0.115	0.098	0.129	0.114	0.090
1	7.39(17)	1.80(16)		140	170	158	0.126	0.112	0.091	0.126	0.110	0.086
4	7.39(17)	1.80(16)		140	170	169	0.127	0.112	0.089	0.133	0.114	0.091

(cont'd)

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[a]Control springs were compressed for a comparable period of time at 140°R.

Table 5-31 (cont'd)

Spring No.	Neutron Fluence (n/cm^2) E > 1 MeV	E < 0.48 eV	Height at 540^oR (in.)	Test Temp.	Load (lb) at 0.081 in. Height		Height (in.) at Given Load (lb)					
							Pre			Post		
					Pre	Post	50	100	150	50	100	150
				Springs uncompressed.								
13	Control		0.154	540	167	157	0.127	0.111	0.093	0.127	0.111	0.085
14	Control		0.157	540	172	170	0.129	0.113	0.096	0.131	0.116	0.094
15	Control		0.156	540	181	164	0.134	0.113	0.099	0.131	0.112	0.090
16	Control		0.150	540	176	163	0.128	0.114	0.098	0.130	0.112	0.089
13	Control			140	164	149	0.127	0.111	0.089	0.126	0.109	-
14	Control			140	170	164	0.128	0.112	0.090	0.128	0.112	0.087
15	Control			140	177	165	0.131	0.114	0.095	0.129	0.114	0.088
16	Control			140	175	164	0.127	0.114	0.095	0.128	0.113	0.087

Table 5-32

FREE LENGTH AND SPRING CONSTANT FOR A-286 SPRINGS
(Specification RTS-58)

Crosshead Speed = 0.50 in./min

Spring No.	Irrad. Temp (°R)	Test Temp (°R)	Preirradiation			Postirradiation			Neutron Fluence (n/cm^2)	
			Free Length (in.)	Spring Const. (lb/in.)[a] 3.292 in.	Spring Const. (lb/in.)[a] 2.754 in.	Free Length (in.)	Spring Const. (lb/in.)[a] 3.292 in.	Spring Const. (lb/in.)[a] 2.754 in.	E > 1 MeV	E < 0.48 eV
15[b]	140	140	3.865	58.5	63.0	3.855	57.9	63.1	Control	
		540	3.895	52.7	62.2	3.882	53.1	60.0		
18[b]	140	140	3.863	59.2	66.7	3.853	58.6	64.9	Control	
		540	3.885	55.0	62.8	3.875	54.4	60.7		
2	140	140	3.865	58.5	65.0	3.842	57.3	64.0	4.30(17)	1.8(16)
		540	3.893	53.7	60.4	3.878	52.6	60.1		
9	140	140	3.860	59.2	60.9	3.852	57.1	59.9	4.30(17)	1.8(16)
		540	-	-	-	3.882	52.5	55.9		
11	140	140	3.862	59.5	63.6	3.842	58.2	63.1	4.30(17)	1.8(16)
		540	3.885	54.5	58.8	3.858	54.7	58.2		
10[b]	540	540	3.900	54.8	61.1	3.876	54.5	60.0	Control	
1	540	540	3.890	54.2	56.8	3.863	53.2	56.6	8.34(17)	2.0(16)
6	540	540	3.902	53.6	59.1	3.845	54.6	59.4	8.34(17)	2.0(16)
12	540	540	3.900	53.0	59.0	3.876	52.9	56.1	8.34(17)	2.0(16)
14[b]	1200	540	3.880	54.3	57.6	3.876	52.7	57.0	Control	
3	1200	540	3.892	53.5	56.4	c			9.64(17)	2.0(16)
13	1200	540	3.895	53.4	57.7	c			9.64(17)	2.0(16)
16	1200	540	3.901	54.5	63.6	c			9.64(17)	2.0(16)

Specimen configuration: WANL Dwg. 388D992
Data to be used for material evaluation only. Do not use for design.

[a]Constant at spring lengths of 3.292 and 2.754 in. Springs were compressed to a length of 2.754 in. for irradiation.
[b]The control springs were maintained at the same temperature as the irradiated springs for a comparable period of time.
[c]Springs could not be removed from the bolts used to compress them because of galling of the threads.

5.6 Tensile and Flexure Data for Feuralon

The Feuralon plastic material was tested in the form of tensile specimens (M-14-1) and flexure specimens (M-14-2). The test procedures were essentially as described for the metal tensile and flexure specimens. The specimens were irradiated in liquid hydrogen.

Table 5-33 gives the tensile data. Since the material does not yield, only the maximum (or ultimate) load and stress were obtained.

The maximum fiber stress given in Table 5-34 was computed by use of Equation 5-6 with an L (span) of 4 in. The deflection of the beam at rupture was determined from the chart travel with the Instron operating at a constant crosshead speed; this is given as "Chart Deflection" in Table 5-34.

Table S-3 of the Summary gives the percent difference between data for the irradiated specimens and indicates if the difference is statistically significant at the 95% confidence level.

Table 5-33
TENSILE DATA FOR FEURALON IRRADIATED AT 40°R TO A GAMMA DOSE OF 4.3 x 10^9 RAD(C) AND TESTED AT 140°R AND 540°R
(Specification M-14-1)

Crosshead Speed = 0.050 in./min

Specimen No.	Test Temp (°R)	Ave Diam (in.)	Area (in^2)	Max Load (lb)	Max Stress (ksi)	Neutron Fluence (n/cm^2) E > 1 MeV	Neutron Fluence (n/cm^2) E < 0.48 eV
Lot A							
4	140	0.2462	0.0476	808	17.0	Control	
13	140	0.2502	0.0491	688	14.0	Control	
16	140	0.2519	0.0498	747	15.0	Control	
5	140	0.2483	0.0484	782	16.1	Control	
Ave				756	15.5		
Std Dev				51.9	1.3		
% Std Dev				6.9	8.4		
7	140	0.2473	0.0480	659	13.7	2.68 (16)	3.0 (16)
3	140	0.2464	0.0477	686	14.4	2.68 (16)	3.0 (16)
12	140	0.2497	0.0490	637	13.0	2.68 (16)	3.0 (16)
2	140	0.2484	0.0485	600	12.4	2.68 (16)	3.0 (16)
Ave				645	13.4		
Std Dev				36.4	0.9		
% Std Dev				5.6	6.5		
15	540	0.2499	0.0490	457	9.3	Control	
14	540	0.2487	0.0486	469	9.7	Control	
11	540	0.2481	0.0483	388	8.0	Control	
10	540	0.2476	0.0481	542	11.3	Control	
Ave				464	9.6		
Std Dev				63.1	1.4		
% Std Dev				13.6	14.2		
9	540	0.2473	0.0480	434	9.0	2.68 (16)	3.0 (16)
6	540	0.2488	0.0486	442	9.1	2.68 (16)	3.0 (16)

Table 5-33
TENSILE DATA FOR FEURALON IRRADIATED AT 40°R TO A GAMMA DOSE OF 4.3 x 10^9 RAD(C) AND TESTED AT 140°R AND 540°R (Cont'd)
(Specification M-14-1)

Specimen No.	Test Temp (°R)	Ave Diam (in.)	Area (in^2)	Max Load (lb)	Max Stress (ksi)	Neutron Fluence (n/cm^2) E > 1 MeV	Neutron Fluence (n/cm^2) E < 0.48 eV
1	540	0.2480	0.0483	479	9.9	2.68 (16)	3.0 (16)
8	540	0.2490	0.0487	477	9.8	2.68 (16)	3.0 (16)
Ave				458	9.5		
Std Dev				23.3	0.5		
% Std Dev				5.1	4.9		
<u>Lot B</u>							
41	140	0.2493	0.0488	890	18.2	Control	
43	140	0.2507	0.0493	833	16.9	Control	
36	140	0.2494	0.0488	838	17.2	Control	
35	140	0.2499	0.0490	778	15.9	Control	
Ave				835	17.1		
Std Dev				45.8	0.9		
% Std Dev				5.5	5.6		
38	140	0.2485	0.0485	765	15.8	2.67 (16)	3.0 (16)
34	140	0.2499	0.0490	743	15.2	2.66 (16)	3.0 (16)
39	140	0.2478	0.0482	793	16.4	2.65 (16)	3.0 (16)
45	140	0.2497	0.0490	740	15.1	2.64 (16)	3.0 (16)
Ave				760	15.6		
Std Dev				24.5	0.6		
% Std Dev				3.2	3.9		
40	540	0.2496	0.0489	399	8.2	Control	
46	540	0.2465	0.0477	582	12.2	Control	
33	540	0.2490	0.0487	531	10.9	Control	

Table 5-33

TENSILE DATA FOR FEURALON IRRADIATED AT 40°R TO A GAMMA DOSE OF 4.3 x 10^9 RAD(C) AND TESTED AT 140°R AND 540°R (Cont'd)

(Specification M-14-1)

Specimen No.	Test Temp (°R)	Ave Diam (in.)	Area (in^2)	Max Load (lb)	Max Stress (ksi)	Neutron Fluence (n/cm^2) E > 1 MeV	Neutron Fluence (n/cm^2) E < 0.48 eV
31	540	0.2475	0.0481	546	11.4	Control	
Ave				514	10.7		
Std Dev				79.9	1.7		
% Std Dev				15.5	16.3		
42	540	0.2497	0.0490	521	10.6	2.63 (16)	3.0 (16)
44	540	0.2468	0.0478	530	11.1	2.62 (16)	3.0 (16)
37	540	0.2478	0.0482	560	11.6	2.61 (16)	3.0 (16)
32	540	0.2503	0.0492	521	10.6	2.60 (16)	3.0 (16)
Ave				533	11.0		
Std Dev				18.5	0.5		
% Std Dev				3.5	4.4		

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Table 5-34

FLEXURE DATA FOR FEURALON IRRADIATED AT 40°R TO A GAMMA DOSE OF 3.5 x 10^9 RAD(C) AND TESTED AT 140°R AND 540°R

(Specification M-14-2)

Crosshead Speed = 0.050 in./min

Specimen No.	Test Temp (°R)	Width (in.)	Thickness (in.)	Chart Deflection (in.)	Max Load (lb)	Max Fiber Stress (ksi)	Neutron Fluence (n/cm^2) E > 1 MeV	Neutron Fluence (n/cm^2) E < 0.48 eV
Lot A								
10	140	0.5020	0.2516	0.2750	96.4	18.2	Control	
8	140	0.5019	0.2520	0.2250	80.6	15.2	Control	
12	140	0.4987	0.2520	0.3125	117.4	22.2	Control	
11	140	0.5064	0.2499	0.3025	110.3	20.9	Control	
9	140	0.5002	0.2496	0.2800	93.0	17.9	Control	
Ave				0.2790	99.5	18.9		
Std Dev				0.0339	14.5	2.7		
% Std Dev				12.2	14.6	14.5		
5	140	0.4974	0.2521	0.2725	106.5	20.2	2.18 (16)	3.0 (16)
17	140	0.4999	0.2460	0.2850	102.8	20.4	2.17 (16)	3.0 (16)
2	140	0.4986	0.2441	0.3000	113.3	22.9	2.16 (16)	3.0 (16)
7	140	0.4962	0.2507	0.2625	101.6	19.5	2.15 (16)	3.0 (16)
20	140	0.4998	0.2467	0.2775	102.0	20.1	2.14 (16)	3.0 (16)
14	140	0.5014	0.2514	0.2800	109.1	20.7	2.13 (16)	3.0 (16)
Ave				0.2796	105.9	20.6		
Std Dev				0.0126	4.7	1.2		
% Std Dev				4.5	4.4	5.7		
23	540	0.5003	0.2493	0.5325	79.9	15.4	Control	
4	540	0.5024	0.2534	0.3075	52.5	9.8	Control	
19	540	0.4993	0.2509	0.3800	68.6	13.1	Control	
18	540	0.5020	0.2466	0.5000	75.0	14.7	Control	

Table 5-34
FLEXURE DATA FOR FEURALON IRRADIATED AT 40°R TO A GAMMA DOSE OF 3.5 x 10^9 RAD(C)
AND TESTED AT 140°R AND 540°R (Cont'd)
(Specification M-14-2)

Specimen No.	Test Temp (°R)	Width (in.)	Thickness (in.)	Chart Deflection (in.)	Max Load (lb)	Max Fiber Stress (ksi)	Neutron Fluence (n/cm^2) E > 1 MeV	Neutron Fluence (n/cm^2) E < 0.48 eV
1	540	0.5038	0.2496	0.2725	96.0	18.4	Control	
6	540	0.5024	0.2517	0.4400	74.3	14.0	Control	
15	540	0.5020	0.2520	0.4950	69.0	13.0	Control	
Ave				0.4189	73.6	14.1		
Std Dev				0.0997	13.1	2.6		
% Std Dev				23.8	17.8	18.6		
24	540	0.5016	0.2475	0.3250	66.0	12.9	2.12 (16)	3.0 (16)
21	540	0.4991	0.2528	0.3000	64.1	12.1	2.11 (16)	3.0 (16)
3	540	0.5047	0.2529	0.4625	79.5	14.8	2.10 (16)	3.0 (16)
22	540	0.4995	0.2467	0.3900	72.4	14.3	2.09 (16)	3.0 (16)
16	540	0.4975	0.2514	0.3825	74.3	14.2	2.08 (16)	3.0 (16)
13	540	0.4971	0.2506	0.4425	80.3	15.4	2.08 (16)	3.0 (16)
Ave				0.3838	72.8	14.0		
Std Dev				0.0635	6.7	1.2		
% Std Dev				16.5	9.2	8.8		
Lot B								
37	140	0.4998	0.3039	0.2750	182.3	23.7	Control	
31	140	0.4995	0.3044	0.2625	171.4	22.2	Control	
42	140	0.5007	0.3035	0.2750	198.8	25.9	Control	
35	140	0.4983	0.3059	0.2900	199.9	25.7	Control	
Ave				0.2756	188.1	24.4		
Std Dev				0.0113	13.7	1.8		
% Std Dev				4.1	7.3	7.2		

Table 5-34
FLEXURE DATA FOR FEURALON IRRADIATED AT 40°R TO A GAMMA DOSE OF 3.5 x 10^9 RAD(C) AND TESTED AT 140°R AND 540°R (Cont'd)
(Specification M-14-2)

Specimen No.	Temp (°R)	Width (in.)	Thickness (in.)	Chart Deflection (in.)	Max Load (lb)	Max Fiber Stress (ksi)	Neutron Fluence (n/cm^2) E > 1 MeV	E < 0.48 eV
40	140	0.5005	0.3045	0.2475	168.8	21.8	2.08 (16)	3.0 (16)
34	140	0.5015	0.3057	0.2700	186.4	23.9	2.08 (16)	3.0 (16)
39	140	0.5009	0.3024	0.2550	172.5	22.6	2.08 (16)	3.0 (16)
38	140	0.5014	0.3047	0.2250	150.8	19.4	2.08 (16)	3.0 (16)
Ave				0.2569	169.6	21.9		
Std Dev				0.0094	14.7	1.9		
% Std Dev				3.7	8.6	8.6		
46	540	0.5021	0.3043	0.4625	128.3	16.6	Control	
32	540	0.4988	0.3053	0.3875	117.0	15.1	Control	
45	540	0.5014	0.3050	0.4850	132.8	17.1	Control	
33	540	0.5016	0.3051	0.3475	115.5	14.8	Control	
Ave				0.4206	123.4	15.9		
Std Dev				0.0641	8.5	1.1		
% Std Dev				15.2	6.9	7.1		
44	540	0.5029	0.3054	0.3300	118.1	15.1	2.08 (16)	3.0 (16)
36	540	0.5005	0.3035	0.3850	126.8	16.5	2.08 (16)	3.0 (16)
43	540	0.5008	0.3048	0.3800	128.6	16.6	2.08 (16)	3.0 (16)
41	540	0.4988	0.3031	0.3200	114.0	14.9	2.08 (16)	3.0 (16)
Ave				0.3538	121.9	15.8		
Std Dev				0.0335	7.0	0.9		
% Std Dev				9.5	5.7	5.7		

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5.7 Data for Actuator Lubricant

The solid-film lubricant evaluated in this study was formulated and applied to the test specimens by Ball Brothers Research Corporation, Boulder, Colorado. The lubricant is known as "Vac Kote" and its formulation is proprietary.

Test specimens were irradiated in liquid hydrogen and were subsequently tested at temperatures of 540° and $1000^{\circ}R$. Results of the sliding wear tests are presented in Tables 5-35 and 5-36.

Friction measurements were made during all runs and the test machine was adjusted to cut off automatically when the friction coefficient reached 0.4. The 0.4 friction coefficient is an arbitrary value selected as the failure point in previous wear-life studies at NARF. Because other investigators often select a lower friction value as the failure point, wear-life (cycles) at friction coefficients of 0.1, 0.2, and 0.3 are also reported.

In performing the sliding wear tests, the load was applied after the machine was at operating speed (355 rpm). In the tests at elevated temperature ($1000^{\circ}R$), the machine was started and the load applied prior to reaching test temperature in order to prevent plastic deformation of the film surface by the rub shoes while coming to temperature. Test temperature was reached during the first 4000 cycles in all cases.

In all runs on irradiated and control specimens, the friction coefficient was 0.05 to 0.07 when the load was first applied. After a period of 2 to 3 minutes of running, the friction coefficient would drop to 0.02 to 0.04 and remain at this level until just prior to commencement of film failure.

Table 5-35

WEAR-LIFE CHARACTERISTICS OF "VAC-KOTE" SOLID-FILM LUBRICANT AT 540°R

Specimen Number	Film Thickness (10^{-4} in.)	Wear Life (cycles)	Cycles at Friction Coefficient of 0.1	Cycles at Friction Coefficient of 0.2	Cycles at Friction Coefficient of 0.3	Test Date
		Control Specimens				
18	6	59,683	58,000	59,420	59,500	10-8-72
24	8	88,292	81,700	86,100	87,700	10-9-72
11	6	41,118	40,960	41,000	41,000	10-11-72
27	8	60,363	57,750	59,300	59,690	10-12-72
31	8	55,579	55,350	55,460	55,460	10-17-72
16	7	59,413	59,000	59,350	59,360	10-16-72
37	8	*107,495	*106,240	*106,720	*107,390	1-9-73
		Ave 67,421	Ave 65,571	Ave 66,764	Ave 67,157	
*Value included in average						
		Irradiated Specimens				
9	5	130,000	128,300	128,750	130,100	1-16-73
13	6	119,623	117,140	118,270	119,673	1-23-73
6	7	188,118	182,170	184,200	188,100	1-24-73
1	7	137,123	134,350	136,100	137,000	2-15-73
17	8	115,907	113,400	114,600	115,480	12-6-72
19	7	157,318	156,350	156,740	157,318	12-4-72
		Ave 141,348	Ave 138,618	Ave 139,777	Ave 141,278	

Test Conditions: Hohman A-6 machine: load 110 lb/shoe; speed 355 rpm (128 sliding ft/min); substrate 440-C steel; rub shoe, 440-C steel

Table 5-36

WEAR-LIFE CHARACTERISTICS OF "VAC-KOTE" SOLID-FILM LUBRICANT AT 1000°R

Specimen Number	Film Thickness (10^{-4} in.)	Wear Life (cycles)	Cycles at Friction Coefficient of 0.1	0.2	0.3	Test Date
		Control Specimens				
2	7	28,333	26,700	27,500	27,900	10-23-72
34	7	33,894	31,300	32,560	33,400	11-6-72
8	9	27,534	24,730	26,530	26,780	11-29-72
29	9	32,052	26,920	27,900	30,400	2-28-73
20	7	32,090	25,700	27,100	31,900	3-1-73
21	6	26,905	23,320	24,120	26,875	3-2-73
		Ave 30,135	Ave 26,445	Ave 27,618	Ave 29,542	
		Irradiated Specimens				
4	9	30,654	27,280	27,670	28,430	12-21-72
25	8	28,448	27,450	27,860	28,300	1-3-73
10	8	27,332	25,300	25,800	26,110	1-4-73
14	7	30,747	29,220	30,060	30,540	1-4-73
38	8	32,877	28,660	29,310	32,877	1-25-73
30	9	29,183	26,350	26,870	29,130	2-6-73
36	8	30,607	28,900	29,550	29,880	2-12-73
		Ave 29,978	Ave 27,594	Ave 28,160	Ave 29,324	

Test Conditions: Hohman A-6 machine: load 110 lb/shoe; speed 355 rpm (128 sliding ft/min); substrate 440-C steel; rub shoe, 440-C steel

APPENDIX A

PEDIGREE DATA

PEDIGREE DATA FORM TEST M-7-1

ITEM:

I. MATERIAL	P.O. No.	SOURCE	FORM	HEAT NO.	BILLET NO.	SIZE
Al 6061-T6	N 01494 IDO 962852 N 01669	Earle M. Jorgensen Co.	Plate	462862 533301		1 in. thick

SPECIFICATION	FORGE SOURCE	FORGING I.D.	FORGING SIZE	HEAT TREATMENT	HEAT TREAT SOURCE
QQ-A-250/11d	Erle M. Jorgensen Co.			T-6 per MIL-H-6088	Aerojet Liquid Rocket Company

II. SPECIFICATION REQUIREMENTS

CHEMISTRY	C	Mn	Fe	Zn	Si	Cu	Ni	Cr	Al	Ti	Mg	Co	Mo	Cb+Ta	Zr	B	OTHER
MAX		1.2	.7	.25	0.8	.40		.35		.15	.15						.15
MIN		0.8			.40	.15		.15	Bal								

MECH. PROPERTIES	TEMP. °F	STRESS, Ksi	YIELD .2% Ksi	ELONG. %	HEAT TREATMENT	GRAIN SIZE
MAX						
MIN	Ambient	42	35	9	T6	

OTHER

III. PURCHASE ORDER DATA:

Deviations from specification:

P. O. N 01494: None

IV. SOURCE DATA:

Deviations from Purchase Order:

P. O. N 01494: None

V. RECEIVING AND INSPECTION DATA:

Deviations from Purchase Order:

P. O. N 01494: None

VI. NERVA PROCESSING:

Deviation from Fab Order:

IDO 962852: None

P. O. N 01669: None

VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE Date ____

RESULTS: Lot A = Heat 462862, Serial No. 880345 thru 880354

Lot B = Heat 533301, Serial No. 880355 thru 880364

PEDIGREE DATA FORM

ITEM:

I. MATERIAL	P.O. No.	SOURCE	FORM	HEAT NO.	BILLET NO.	SIZE
Ti 6Al4V	N01453 N01661	Universal Titanium Co., Inc.	Sheet	G-50532		1/4" thick

SPECIFICATION	FORGE SOURCE	FORGING I.D.	FORGING SIZE	HEAT TREATMENT	HEAT TREAT SOURCE
MIL-T-9046F, Type III, Composition C	Crucible Steel				

II. SPECIFICATION REQUIREMENTS

CHEMISTRY	V	C	Mn	Fe	N	H	Cu	O	Cr	Al	Ti	Mg	Co	Mo	Cb+Ta	Zr	B	OTHER
MAX	3.5	.08		.30	.05	.015		.20		6.75								.40
MIN	4.5									5.5	Bal							

MECH. PROPERTIES	TEMP. °F	STRESS, Ksi	YIELD .2% Ksi	ELONG. %	HEAT TREATMENT	GRAIN SIZE
MAX						
MIN	Ambient	134	126	8.0		

OTHER

III. PURCHASE ORDER DATA:

Deviations from specification:

P.O. N01453: None

IV. SOURCE DATA:

Deviations from Purchase Order:

P.O. N01453: None

V. RECEIVING AND INSPECTION DATA:

Deviations from Purchase Order:

P.O. N01453 - None

VI. NERVA PROCESSING:

Deviation from Fab Order:

P.O. N01661 - Dimensional discrepancies were reported but will not affect test results

VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE | Date

RESULTS:

Specimens fabricated from rolling direction of plate. Specimen serial numbers are 880001 through 880030.

140°R unirradiated properties

Max strength 209 ksi

.2% yield strength 202 ksi

PEDIGREE DATA FORM

Test M-9-2

ITEM:

I. MATERIAL	P.O. No.	SOURCE	FORM	HEAT NO.	BILLET NO.	SIZE
Ti 6Al 4V	N 01897 N 01947 N 01695	Universal Titanium Co., Inc.	Plate welded	C50532		1/4" thick

SPECIFICATION	FORGE SOURCE	FORGING I.D.	FORGING SIZE	HEAT TREATMENT	HEAT TREAT SOURCE
MIL-T-9046 Type III, Composition C				Weld per MIL-T-5021 and AGC-STD-1194-12B	Airline Welding and Engineering

II. SPECIFICATION REQUIREMENTS

CHEMISTRY	V	C	Mn	Fe	N_2	H_2	O_2	Ni	Cr	Al	Ti	Mg	Co	Mo	Cb+Ta	Zr	B	OTHER
MAX	4.5	0.08		0.30	0.05	.015	0.20			6.75								0.40
MIN	3.5									5.5	Bal							

MECH. PROPERTIES	TEMP. °F	STRESS, Ksi	YIELD .2% Ksi	ELONG. %	HEAT TREATMENT	GRAIN SIZE
MAX					Stress relieve at 1100°F for 2 hours	
MIN						

OTHER

III. PURCHASE ORDER DATA: P. O. N 01897

Deviations from specification:

P. O. N 01897 - None

IV. SOURCE DATA: P. O. N 01897

Deviations from Purchase Order:

P. O. N 01897 - None

V. RECEIVING AND INSPECTION DATA: P. O. N 01897

Deviations from Purchase Order:

P. O. N 01897 - None

VI. NERVA PROCESSING: P. O. N 01947 P. O. N 01695

Deviation from Fab Order:

P. O. N 01947 - Parts of weldment were porous but these parts were not used to fabricate specimens.

P. O. N 01695 - Specimens do not meet flatness requirement. They were bowed up to .005 inch from end to end.

VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE

Date

RESULTS: Serial Numbers are 880046 thru 880060.

PEDIGREE DATA FORM   Test M-9-3

ITEM:

I. MATERIAL	P.O. No.	SOURCE	FORM	HEAT NO.	BILLET NO.	SIZE
Ti 6Al-4V	N01897 IDO 961115 N01947 N01695	Universal Titanium Co., Inc.	Plate welded	G-50532		1/4" thick

SPECIFICATION	FORGE SOURCE	FORGING I.D.	FORGING SIZE	HEAT TREATMENT	HEAT TREAT SOURCE
MIL-T-9046F Type III Composition C	Crucible Steel			Weld per MIL-T-5021 and AGC-STD-1194-12B	Airline Welding and Engineering

II. SPECIFICATION REQUIREMENTS

CHEMISTRY	V	C	Mn	Fe	N	H	O	Ni	Cr	Al	Ti	Mg	Co	Mo	Cb+Ta	Zr	B	OTHER
MAX	4.5	0.08		0.30	0.05	.015	0.20			6.75								0.40
MIN	3.5									5.5	Bal							

MECH. PROPERTIES	TEMP. °F	STRESS, Ksi	YIELD .2% Ksi	ELONG. %	HEAT TREATMENT	GRAIN SIZE
MAX					Stress Relieve 1100°F for 2 hours	
MIN						

OTHER

III. PURCHASE ORDER DATA:

Deviations from specification:

PO N01897: None

IV. SOURCE DATA:

Deviations from Purchase Order:

PO N01897: None

V. RECEIVING AND INSPECTION DATA:

Deviations from Purchase Order:

PO N01897: None

VI. NERVA PROCESSING:

Deviation from Fab Order:

PO N01947: Porous areas in parent material. Porous areas not used.

PO N01695: Parts are bowed end to end from .007/.010.

IDO 961115: None

VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE   Date

RESULTS: Serial numbers are S/N 880007 thru 880021.

PEDIGREE DATA FORM

ITEM:

I. MATERIAL	P.O. No.	SOURCE	FORM	HEAT NO.	BILLET NO.	SIZE
Feuralon	N00714 N01358	Bemal Corp	Sheet			1/4 x 10 x 10 .3 x 6 x 10

SPECIFICATION	FORGE SOURCE	FORGING I.D.	FORGING SIZE	HEAT TREATMENT	HEAT TREAT SOURCE
Type AW					

II. SPECIFICATION REQUIREMENTS

CHEMISTRY	C	Mn	Fe	S	Si	Cu	Ni	Cr	Al	Ti	Mg	Co	Mo	Cb+Ta	Zr	B	OTHER
MAX																	
MIN																	

MECH. PROPERTIES	TEMP. °F	STRESS, Ksi	YIELD .2% Ksi	ELONG. %	HEAT TREATMENT	GRAIN SIZE
MAX						
MIN						

OTHER: Fabricate to Drawing 1139068-15 N/C

III. PURCHASE ORDER DATA: Lot 1 PO N00714; Lot 2 PO N01358

Deviations from specification:

PO N00714 - None

PO N01358 - None

V. RECEIVING AND INSPECTION DATA:

Deviations from Purchase Order:

PO N00714 - Thickness varied from .250 to .420 inch

PO N01358 - Thickness varied from .370 to .440 inch

IV. SOURCE DATA:

Deviations from Purchase Order:

PO N00714 - None

PO N01358 - None

VI. NERVA PROCESSING: Lot 1 PO N01252; Lot 2 PO N01528

Deviation from Fab Order:

PO N01252 - Specimens ↗ up to .008 (should be .002 max.) and ⊕ up to .012 (should be .002 max.)

PO N01528 - S/N 16 $\boxed{\oplus \text{ A } .010}$ is .022. It should be .010 max.

VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND, TEST CHECKOUT FOR TEST AGENCY USE ____ Date ____

RESULTS: Lot 1 S/N 01 thru 16

Lot 2 S/N 31 thru 46

Serialization:

As purchased, Lot 1 consisted of S/N 1 thru 16 and Lot 2 consisted of S/N 880001 thru 880016. Lot 2 was reserialized S/N 31 thru 46 as indicated above to facilitate GTR-23 testing.

APPENDIX A

Test M-14-2

PEDIGREE DATA FORM

ITEM:

I. MATERIAL	P.O. No.	SOURCE	FORM	HEAT NO.	BILLET NO.	SIZE
Feuralon	N00714 N01358	Bemol Corp	Sheet			1/4"x10"x10" .300x 6"x10"

SPECIFICATION	FORGE SOURCE	FORGING I.D.	FORGING SIZE	HEAT TREATMENT	HEAT TREAT SOURCE
Type AW					

II. SPECIFICATION REQUIREMENTS

CHEMISTRY	C	Mn	Fe	S	Si	Cu	Ni	Cr	Al	Ti	Mg	Co	Mo	Cb+Ta	Zr	B	OTHER
MAX																	
MIN																	

MECH. PROPERTIES	TEMP. °F	STRESS, Ksi	YIELD .2% Ksi	ELONG. %	HEAT TREATMENT	GRAIN SIZE
MAX						
MIN						

OTHER: Fabricate to Drawing 1138147-15B

III. PURCHASE ORDER DATA: Lot 1 PO N00714
Lot 2 PO N01358

Deviations from specification:

PO N00714 - None
PO N01358 - None

V. RECEIVING AND INSPECTION DATA:

Deviations from Purchase Order:

PO N00714 - Thickness varied from .250 to .420 in.
PO N01358 - Thickness varied from .370 to .440 in.

IV. SOURCE DATA:

Deviations from Purchase Order:

PO N00714 - None
PO N01358 - None

VI. NERVA PROCESSING: Lot 1 PO N01252
Lot 2 PO N01528

Deviation from Fab Order:

PO N01252 - Specimen are up to .020 inches short and parallelity is up to .006 (should be .002 max.)

PO N01528 - Specimen ⊥ and ∥ required to be .002 max. Actuals are up to .007.

VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE ____Date ____

RESULTS: Lot 1 S/N 1 thru 24
Lot 2 S/N 31 thru 46

Serialization:

As purchased, Lot 1 consisted of S/N 21 thru 36 and 40 thru 47. Lot 2 consisted of S/N 880029 thru 880044. They were reserialized to S/N 1 thru 24 and 31 thru 46 as indicated above to facilitate GTR-23 testing.

Test M-16-1

PEDIGREE DATA FORM

ITEM:

I. MATERIAL	P.O. No.	SOURCE	FORM	HEAT NO.	BILLET NO.	SIZE
18 Ni Maraging Steel	N 01655 IDO961146 N01175 N 01529	Vasco Pacific Steel	Plate	04642 1634A		.75" X 12" X 24"

SPECIFICATION	FORGE SOURCE	FORGING I.D.	FORGING SIZE	HEAT TREATMENT	HEAT TREAT SOURCE
Bendix Corp. Fluid Division. Spec. E18-V	Teledyne Vasco			Age 3 hrs at 900°F	Aerojet Liquid Rocket Co.

II. SPECIFICATION REQUIREMENTS

CHEMISTRY	C	Mn	Fe	S	Si	Cu	Ni	Cr	Al	Ti	Mg	Co	Mo	Cb+Ta	Zr	B	OTHER
~~MAX~~ Typical	.018	.03	Bal	.004	.04		18.47		.13	.50		8.40	4.92		.011	.003	.05
~~MIN~~																	

MECH. PROPERTIES	TEMP.°F	STRESS, Ksi	YIELD .2% Ksi	ELONG. %	HEAT TREATMENT	GRAIN SIZE
MAX						
MIN						

OTHER

III. PURCHASE ORDER DATA:

P.O. N 01175
P.O. N 01655

Deviations from specification:

P.O. N 01175 - None

P.O. N 01655 - None

V. RECEIVING AND INSPECTION DATA:

P.O. N 01175
P.O. N 01655

Deviations from Purchase Order:

P.O. N 01175 - None

P.O. N 01655 - None

IV. SOURCE DATA:

P.O. N 01175
P.O. N 01655

Deviations from Purchase Order:

P.O. N 01175 - None

P.O. N 01655 - None

VI. NERVA PROCESSING:

P.O. N 01529
IDO 961146

Deviation from Fab Order:

P.O. N 01529 - None

IDO 961146 - None

VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE

Date ____

RESULTS: Lot 1 Purchased on P.O. N 01655, S/N 880168 thru 880173.

Lot 2 Purchased on P.O. N 01175, S/N 880174 thru 880179.

Unirradiated room temperature tensile properties.

Ultimate Strength = 266 KSI

Yield Strength = 259 KSI

Elongation = 10%

Test M-16-2

PEDIGREE DATA FORM

ITEM:

I. MATERIAL	P.O. No.	SOURCE	FORM	HEAT NO.	BILLET NO.	SIZE
18 Ni Maraging Steel	N 01655 N 01425 N 01175 IDO 961114 N 01529	Vasco Pacific Steel	Plate	04642 1634A		.75"X 12" X 24"

SPECIFICATION	FORGE SOURCE	FORGING I.D.	FORGING SIZE	HEAT TREATMENT	HEAT TREAT SOURCE
Bendix Corp. Fluid Division Spec. E18-V	Teledyne Vasco			Age 3 hours at 900°F	Aerojet Liquid Rocket Co.

II. SPECIFICATION REQUIREMENTS

CHEMISTRY	C	Mn	Fe	S	Si	Cu	Ni	Cr	Al	Ti	Mg	Co	Mo	Cb+Ta	Zr	B	OTHER
~~MAX~~ Typical	.018	.03	Bal	.004	.04		18.47		.13	.50		8.40	4.92		.011	.003	.05
MIN																	

MECH. PROPERTIES	TEMP.°F	STRESS, Ksi	YIELD .2% Ksi	ELONG. %	HEAT TREATMENT	GRAIN SIZE
MAX						
MIN						

OTHER

III. PURCHASE ORDER DATA:

P.O. N 01175
P.O. N 01655

Deviations from specification:

P.O. N 01175 - None
P.O. N 01655 - None

V. RECEIVING AND INSPECTION DATA:

P.O. N 01175
P.O. N 01655

Deviations from Purchase Order:

P.O. N 01175 - None
P.O. N 01655 - None

IV. SOURCE DATA:

P.O. N 01175
P.O. N 01655

Deviations from Purchase Order:

P.O. N 01175 - None
P.O. N 01655 - None

VI. NERVA PROCESSING:

P.O. N 01425
P.O. N 01529
IDO 961114

Deviation from Fab Order:

P.O. N 01425 - None
P.O. N 01529 - None
IDO 961114 - None

VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE

Date ____

RESULTS: Lot A = Material purchased on P.O. N 01655; S/N 880027 thru 880038 and 880114 thru 880131

Lot B = Material purchased on P.O. N 01175; S/N 880251 thru 880280

Max load at 300 cycles per minute is expected to be less than 7000 pounds.

PEDIGREE DATA FORM

TEST M-21-1

ITEM:

I. MATERIAL	P.O. No.	SOURCE	FORM	HEAT NO.	BILLET NO.	SIZE
Al 7075-T73	N 00655 N 01584	Wyman-Gordon Company	Forging			

SPECIFICATION	FORGE SOURCE	FORGING I.D.	FORGING SIZE	HEAT TREATMENT	HEAT TREAT SOURCE
MIL-A-22771/B	Wyman-Gordon Company	57" at base 48" at top	49 1/2" at base 50 1/2 at top 18 1/2" high	T-73	Wyman-Gordon Company

II. SPECIFICATION REQUIREMENTS

CHEMISTRY	Zn	Mn	Fe	S	Si	Cu	Ni	Cr	Al	Ti	Mg	Co	Mo	Cb+Ta	Zr	B	OTHER
MAX	6.1	0.30	0.7		0.50	2.0		0.40		0.20	2.9						0.15
MIN	5.1					1.2		0.18	Bal		2.1						

MECH. PROPERTIES	TEMP. °F	STRESS, Ksi	YIELD .2% Ksi	ELONG. %	HEAT TREATMENT	GRAIN SIZE
MAX						
MIN	Room Temp	62	53	3	T-73	

OTHER

III. PURCHASE ORDER DATA: P.O. N 00655

Deviations from specification:

None

V. RECEIVING AND INSPECTION DATA: P.O. N 00655

Deviations from Purchase Order:

None

IV. SOURCE DATA: P.O. N 00655

Deviations from Purchase Order:

Stress corrosion tests deleted per SIR 1017

VI. NERVA PROCESSING: P.O. N 01584

Deviation from Fab Order:

Specimens identified by vibro peen per SIR 11690

VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE

Date

RESULTS: Specimens from forging #1, S/N 880156 thru 880167.

140°R unirradiated properties

Max strength 90 ksi

.2% yield strength 70 ksi

Elongation 13%

PEDIGREE DATA FORM

Test M-21-2

ITEM:

I. MATERIAL	P.O. No.	SOURCE	FORM	HEAT NO.	BILLET NO.	SIZE
Al 7075-T73	N00655 N01584 IDO 961115	Wyman-Gordon Co.	Forging			

SPECIFICATION	FORGE SOURCE	FORGING I.D.	FORGING SIZE	HEAT TREATMENT	HEAT TREAT SOURCE
MIL-A-22771/B	Wyman-Gordon Company	57" at Base 48" at Top	49 1/2" at Base 50 1/2" at Top 18 1/2" High	T-73	Wyman-Gordon Company

II. SPECIFICATION REQUIREMENTS

CHEMISTRY	Zn	Mn	Fe	S	Si	Cu	Ni	Cr	Al	Ti	Mg	Co	Mo	Cb+Ta	Zr	B	OTHER
MAX	6.1	0.30	0.7		0.50	2.0		0.40		0.20	2.9						0.15
MIN	5.1					1.2		0.18	Bal		2.1						

MECH. PROPERTIES	TEMP. °F	STRESS, Ksi	YIELD .2% Ksi	ELONG. %	HEAT TREATMENT	GRAIN SIZE
MAX						
MIN	Ambient	62	53	3	T-73	

OTHER

III. PURCHASE ORDER DATA:

Deviations from specification:

PO N00655: None

V. RECEIVING AND INSPECTION DATA:

Deviations from Purchase Order:

PO N00655: None

IV. SOURCE DATA:

Deviations from Purchase Order:

PO N00655: Stress corrosion tests deleted per SIR 1017.

VI. NERVA PROCESSING:

Deviation from Fab Order:

PO N01584: Specimens identified by vibro peen per SIR 11690.

IDO 961115: Fatigue cracks on 5 specimens were extended per IR 512463.

VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE ______Date ____

RESULTS: Lot A specimens from Forging # 1 are S/N 880301 through 880312 and 880381 through 880388.

Lot B specimens from Forging #2 are S/N 880333 through 880344 and 880411 through 880417.

PEDIGREE DATA FORM

Test M-21-4

ITEM:

I. MATERIAL	P.O. No.	SOURCE	FORM	HEAT NO.	BILLET NO.	SIZE
Al 7075-T73 with Al flame spray coating	N 01517 N 01881 N 01948	Pacific Metals Division, A.M. Castle Co.	Sheet	53880		.187" x 48" x 18"

SPECIFICATION	FORGE SOURCE	FORGING I.D.	FORGING SIZE	HEAT TREATMENT	HEAT TREAT SOURCE
QQ-A-250/12d				T 73	Industrial Heat Treatment

II. SPECIFICATION REQUIREMENTS

CHEMISTRY	Zn	C	Mn	Fe	S	Si	Cu	Ni	Cr	Al	Ti	Mg	Co	Mo	Cb+Ta	Zr	B	OTHER
MAX	6.1		0.30	0.7		0.50	2.0		0.40		0.20	2.9						0.15
MIN	5.1						1.2		0.18	Bal		2.1						

MECH. PROPERTIES	TEMP.°F	STRESS, Ksi	YIELD .2% Ksi	ELONG. %	HEAT TREATMENT	GRAIN SIZE
MAX						
MIN						

OTHER

III. PURCHASE ORDER DATA: P. O. N 01517

Deviations from specification:

P. O. N 01517 - None

IV. SOURCE DATA: P. O. N 01517

Deviations from Purchase Order:

P. O. N 01517 - None

V. RECEIVING AND INSPECTION DATA: P. O. N 01517

Deviations from Purchase Order:

P.O. N 01517 - Sheet not stamped with identification prior to heat treatment. Dispositioned conditionally accept for tests other than base metal properties testing.

VI. NERVA PROCESSING: P. O. N 01881 P. O. N 01948

Deviation from Fab Order:

P. O. N 01881 - None

P. O. N 01948 - SIR 1042 authorizes use of equipment developed after flame spray specification was prepared.

VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE ____Date ____

RESULTS: Specimen S/N 88006 thru 880115 fabricated on P. O. N 01881.
Serial numbers 880066 thru 880097 are used for GTR-23

PEDIGREE DATA FORM

Test M-31-1

ITEM:

I. MATERIAL	P.O. No.	SOURCE	FORM	HEAT NO.	BILLET NO.	SIZE
SAE 9310	N00837 N01460 N01953	Erle M. Jorgensen	Bar	3923443		4" dia X 6' long

SPECIFICATION	FORGE SOURCE	FORGING I.D.	FORGING SIZE	HEAT TREATMENT	HEAT TREAT SOURCE
AMS 6265	Republic Steel			Same as test M-31-2 specimens except no carbon used.	Cal Doran

II. SPECIFICATION REQUIREMENTS

CHEMISTRY	P	C	Mn	Fe	S	Si	Cu	Ni	Cr	Al	Ti	Mg	Co	Mo	Cb+Ta	Zr	B	OTHER
MAX	.015	0.13	0.70		.015	0.35	0.35	3.50	1.40					0.15				
MIN		0.07	0.40			0.20		3.00	1.00					0.08				

MECH. PROPERTIES	TEMP.°F	STRESS, Ksi	YIELD .2% Ksi	ELONG. %	HEAT TREATMENT	GRAIN SIZE
MAX						
MIN						

OTHER

III. PURCHASE ORDER DATA:

Deviations from specification:

PO N00837: None

V. RECEIVING AND INSPECTION DATA:

Deviations from Purchase Order:

PO N00837: None

IV. SOURCE DATA:

Deviations from Purchase Order:

PO N00837: None

VI. NERVA PROCESSING:

Deviation from Fab Order:

PO N01460: None

PO N01953: Specimen identification lost during heat treat. Separated into lots by spectographic analysis and re-identified.

PO N02374: None

VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE

Date

RESULTS: Specimen serial numbers are 880001 through 880008.

140°R unirradiated properties

Max strength 210 ksi

.2% yield strength 170 ksi

Elongation 20%

PEDIGREE DATA FORM — Test M-31-2

ITEM:

1. MATERIAL	P.O. No.	SOURCE	FORM	HEAT NO.	BILLET NO.	SIZE
SAE 9310	N 00837 N 01832 N 01452 N 01875 N 01460 IDO 961113 N 01513 IDO 960520	Erle M. Jorgensen Co. Allen Frye Steel	Bar	3923443 3821068		4" Dia x 6' Long

SPECIFICATION	FORGE SOURCE	FORGING I.D.	FORGING SIZE	HEAT TREATMENT	HEAT TREAT SOURCE
AMS 6265	Republic Steel			Carburized to .013/.018" deep, surface hardness of RC 58 minimum.	Cal Doran

II. SPECIFICATION REQUIREMENTS

CHEMISTRY	P	C	Mn	Fe	S	Si	Cu	Ni	Cr	Al	Ti	Mg	Co	Mo	Cb+Ta	Zr	B	OTHER
MAX	.015	0.13	0.70		.015	0.35	0.35	3.50	1.40					0.15				
MIN		0.07	0.40			0.20		3.00	1.00					0.08				

MECH. PROPERTIES	TEMP. °F	STRESS, Ksi	YIELD .2% Ksi	ELONG. %	HEAT TREATMENT	GRAIN SIZE
MAX						
MIN						

OTHER

III. PURCHASE ORDER DATA: P. O. N 00837, P. O. N 01452

Deviations from specification:

P. O. N 00837 - None

P. O. N 01452 - None

V. RECEIVING AND INSPECTION DATA: P. O. N 00837, P. O. N 01452

Deviations from Purchase Order:

P. O. N 00837 - None

P. O. N 01452 - None

IV. SOURCE DATA: P. O. N 00837, P. O. N 01452

Deviations from Purchase Order:

P. O. N 00837 - None

P. O. N 01452 - None

VI. NERVA PROCESSING: P. O. N 01460, P. O. N 01513, IDO 961113, P. O. N 01832, P. O. N 01875, IDO 965020

Deviation from Fab Order:

P. O. N 01460 - None

P. O. N 01513 - None

IDO 961113 - None

P. O. N 01832 - Specimen serial numbers lost during carburization. Lots were separated by spectrial analysis and re-serialized on IDO 960520.

P. O. N 01875 - None

IDO 960520 - None

VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE — Date

RESULTS: Lot A purchased on P.O. N 00837 from Erle M. Jorgensen & Co., Heat 3923443, Serial Numbers 880087 thru 880101 and 880422 thru 880431.

Lot B pruchased on P.O. N 01452 from Allen Frye Steel Co., Heat 3821068, Serial Numbers 880132 thru 880146 and 880432 thru 880441.

Max expected load at 300 cycles per minute is 6000 pounds

PEDIGREE DATA FORM

TEST M-38-1

ITEM:

I. MATERIAL	P.O. No.	SOURCE	FORM	HEAT NO.	BILLET NO.	SIZE
ARMCO 22-13-5	N00090 N 02116 N 00772 S.O.A83296	Aerojet Liquid Rocket Co.	All weld	038096		

SPECIFICATION	FORGE SOURCE	FORGING I.D.	FORGING SIZE	HEAT TREATMENT	HEAT TREAT SOURCE
				1950°F + 1825°F + 1775°F	Pyromet Industries

II. SPECIFICATION REQUIREMENTS

CHEMISTRY	C	Mn	Fe	S	Si	Cu	Ni	Cr	Al	Ti	Mg	Co	Mo	Cb+Ta	Zr	B	OTHER
~~MAX~~ Typical	.037	1.91	Bal	.025	.47		14.18	21.22					2.27				.07
MIN																	

MECH. PROPERTIES	TEMP. °F	STRESS, Ksi	YIELD .2% Ksi	ELONG. %	HEAT TREATMENT	GRAIN SIZE
MAX					Simulated Braze Cycle	
MIN						

OTHER

III. PURCHASE ORDER DATA: P.O. N 00090

Deviations from specification:

None

V. RECEIVING AND INSPECTION DATA: P.O. N 00090

Deviations from Purchase Order:

None

IV. SOURCE DATA: P.O. N 00090

Deviations from Purchase Order:

None

VI. NERVA PROCESSING: P.O. N 02116 P.O. N 00772 S.O. A 83296

Deviation from Fab Order:

S.O. A 83296 - None

P.O. N 00772 - None

P.O. N 02116 - None

VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE   Date ____

RESULTS: Serial Numbers are 1-3, 1-4, 2-3, 2-4, 6-3, 6-4.

Control Data (test at 140°R)

Specimen	Ultimate Strength	0.2% Yield Strength	Elong	R.A.
1-1	158 ksi	97.3 ksi	20%	27.2%
2-1	151 ksi	99.5 ksi	14%	13.1%
6-1	158 ksi	101.0 ksi	16%	11.0%

PEDIGREE DATA FORM

Test M-38-3

ITEM:

I. MATERIAL	P.O. No.	SOURCE	FORM	HEAT NO.	BILLET NO.	SIZE
ARMCO 22-13-5	N-00231 N-02321 N-00952 N-02060	G. O. Carlson, Inc.	Plate	300321-1C		1 1/4" x 8" x 48"

SPECIFICATION	FORGE SOURCE	FORGING I.D.	FORGING SIZE	HEAT TREATMENT	HEAT TREAT SOURCE
				1950°F + 1825°F + 1775°F	Pyromet Industries

II. SPECIFICATION REQUIREMENTS

CHEMISTRY	C	Mn	Fe	S	Si	Cu	Ni	Cr	Al	Ti	Mg	Co	Mo	Cb+Ta	Zr	B	OTHER
~~MAX~~ Typical	.042	4.68	Bal	.010	.41		12.42	21.19					2.22	.16			.73
MIN																	

MECH. PROPERTIES	TEMP. °F	STRESS, Ksi	YIELD .2% Ksi	ELONG. %	HEAT TREATMENT	GRAIN SIZE
MAX					Simulated furnace braze cycles for Phoebus II A nozzle	
MIN						

OTHER

III. PURCHASE ORDER DATA: P.O. N-00231

Deviations from specification:

None

V. RECEIVING AND INSPECTION DATA: P.O. N-00231

Deviations from Purchase Order:

None

IV. SOURCE DATA: P.O. N-00231

Deviations from Purchase Order:

None

VI. NERVA PROCESSING: P.O. N-00952 P.O. N-02060 P.O. N-02321

Deviation from Fab Order:

P.O. N-00952 - None

P.O. N-02060 - None

P.O. N-02321 - None

VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE Date

RESULTS: Specimen serial numbers are 880451 thru 880470.

140°R unirradiated K_{IC} = 84 ksi $\sqrt{in}$

Test M-38-4

PEDIGREE DATA FORM

ITEM:

I. MATERIAL	P.O. No.	SOURCE	FORM	HEAT NO.	BILLET NO.	SIZE
ARMCO 22-13-5	N 00231 N 00952 N 02060	G.O.Carlson, Inc.	Plate	300321-1C		1 1/4" x 8" x 48"

SPECIFICATION	FORGE SOURCE	FORGING I.D.	FORGING SIZE	HEAT TREATMENT	HEAT TREAT SOURCE
				1950°F + 1825°F+ 1775°F	Pyromet Industries

II. SPECIFICATION REQUIREMENTS

CHEMISTRY	C	Mn	Fe	S	Si	Cu	Ni	Cr	Al	Ti	Mg	Co	Mo	Cb+Ta	Zr	B	OTHER
~~XXXX~~ Typical	.042	4.68	Bal	.010	.41		12.42	21.19					2.22	.16			.73
MIN																	

MECH. PROPERTIES	TEMP. °F	STRESS, Ksi	YIELD .2% Ksi	ELONG. %	HEAT TREATMENT	GRAIN SIZE
MAX					Simulated Braze	
MIN						

OTHER

III. PURCHASE ORDER DATA: PO N 00231

Deviations from specification:

None

V. RECEIVING AND INSPECTION DATA: PO N 00231

Deviations from Purchase Order:

None

IV. SOURCE DATA: PO N 00231

Deviations from Purchase Order:

None

VI. NERVA PROCESSING: PO N 00952 PO N 02060

Deviation from Fab Order:

PO N 00952 - None

PO N 02060 - None

VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE | Date

RESULTS: Specimen S/N 880210 thru 880218

Expected tensile properties

Property	3×10^{18} nvt	8×10^{18} nvt
Yield Strength	155 KSI	180 ksi
Maximum Strength	215 KSI	235 KSI
Elongation	15%	12%

PEDIGREE DATA FORM

Test M-39-1

ITEM:

I. MATERIAL	P.O. No.	SOURCE	FORM	HEAT NO.	BILLET NO.	SIZE
BeCu	N-02245	Pacific Spring Engineering Co.	Belleville Springs	4-1076 Lot No 1-9-523		4.7" OD 3.3" ID .162 high

SPECIFICATION	FORGE SOURCE	FORGING I.D.	FORGING SIZE	HEAT TREATMENT	HEAT TREAT SOURCE
Pacific Spring Engineering Co. P/N 10080				600°F for 2 hours	Pacific Spring Engineering Co.

II. SPECIFICATION REQUIREMENTS

CHEMISTRY	Be	C	Mn	Fe	S	Si	Cu	Ni	Cr	Al	Ti	Mg	Co	Mo	Cb+Ta	Zr	B	OTHER
MAX	2.0						Bal	.60										.50
MIN	1.8												.20					

MECH. PROPERTIES	TEMP.°F	STRESS, Ksi	YIELD .2% Ksi	ELONG. %	HEAT TREATMENT	GRAIN SIZE
MAX						
MIN						

OTHER: BeCu alloy 172 per ASTM-B 194, 1/4 hard in precipitation heat treat condition.

III. PURCHASE ORDER DATA: P.O. N-02245

Deviations from specification:

None

V. RECEIVING AND INSPECTION DATA: P.O. N-02245

Deviations from Purchase Order:

None

IV. SOURCE DATA: P.O. N-02245

Deviations from Purchase Order:

None

VI. NERVA PROCESSING: None

Deviation from Fab Order:

VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE

Date

RESULTS: Chemical Analysis

Pb	.004	Zn	.030
Sn	.05	Be	1.87
Si	.09	Co	.21
Cr	.003	Al	.06
Ni	.02	Mn	.009
Cu	Bal	Ag	.015
Fe	.10		

Approximately 190 pounds required to compress spring .100 inch.

PEDIGREE DATA FORM

ITEM:

I. MATERIAL	P.O. No.	SOURCE	FORM	HEAT NO.	BILLET NO.	SIZE
Ti 5Al 2.5Sn ELI	102554 N01874 N01515 N02722 N01550	Wyman-Gordon Co.	Forging			17" dia X 10" long

SPECIFICATION	FORGE SOURCE	FORGING I.D.	FORGING SIZE	HEAT TREATMENT	HEAT TREAT SOURCE
AGC 90163A	Wyman-Gordon Co.		17" dia X 10" long	Vacuum anneal at 1400°F	Wyman-Gordon Co.

II. SPECIFICATION REQUIREMENTS

CHEMISTRY	C	Mn	Fe	N	H	Sn	O	Cr	Al	Ti	Mg	Co	Mo	Cb+Ta	Zr	B	OTHER
MAX	0.05	0.10	0.25	0.04	0.0125	3.00	0.12		5.60	Bal							0.40
MIN	-	-	-	-	-	2.00			4.70	-							-

MECH. PROPERTIES	TEMP. °F	STRESS, Ksi	YIELD .2% Ksi	ELONG. %	HEAT TREATMENT	GRAIN SIZE
MAX	Ambient				Keep material below Beta	
MIN	Ambient	105	95	12	Transformation temperature	

OTHER

III. PURCHASE ORDER DATA:

Deviations from specification:

PO 102554: None

IV. SOURCE DATA:

Deviations from Purchase Order:

PO 102554: None

V. RECEIVING AND INSPECTION DATA:

Deviations from Purchase Order:

PO 102554: None

VI. NERVA PROCESSING:

Deviation from Fab Order:

PO N01515 - None
PO N01550 - None
Req N01874 Fill tube with .020" wall thickness was used; reworked per SDAR 40123 to provide .016" wall in seal-off area.
PO N02722: None

VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE

Date

RESULTS: P/N 1138265 - 104 "B" S/N 880024 thru 880083 per PO N01515
P/N 1139567 - 4 N/C S/N 880001 thru 880045 per PO N01550
P/N 1138791-1 S/N 880024 thru 880033
P/N 1138791-10 S/N 880001 thru 880005

Specimens oriented perpendicular to radial direction of forging.

P/N 1138791-1 and 1138791-10: The capsule walls were swaged to contact specimen button heads to improve heat transfer.

PEDIGREE DATA FORM

ITEM:

I. MATERIAL	P.O. No.	SOURCE	FORM	HEAT NO.	BILLET NO.	SIZE
Hastelloy X	N01109 N01550 N01251 N01874 N01515 N02722	Stellite (Cabot Corp)	Bar	2610-0-4007		.75"X 15'

SPECIFICATION	FORGE SOURCE	FORGING I.D.	FORGING SIZE	HEAT TREATMENT	HEAT TREAT SOURCE
AGC 90056E except weld test				Simulated braze per PO N01251	Pyromet Ind.

II. SPECIFICATION REQUIREMENTS

CHEMISTRY	W	C	Mn	Fe	S	Si	Cu	Ni	Cr	Al	Ti	V	Co	Mo	P	Zr	B	OTHER
MAX	1.00	0.15	1.00	20.00	.015	1.00	0.35	-	23.00	0.02	0.02	0.50	2.50	10.00	.020	0.02	.001	
MIN	0.20	0.05	-	17.00	-	-	-	Bal	20.50	-	-	-	0.50	8.00	-	-	-	

MECH. PROPERTIES	TEMP. °F	STRESS, Ksi	YIELD .2% Ksi	ELONG. %	HEAT TREATMENT	GRAIN SIZE
MAX					Anneal at 2000°F for 60 minutes	60% finer than No. 6 100% finer than No. 3
MIN						
OTHER						

III. PURCHASE ORDER DATA: PO N01109 PO N01251

Deviations from specification:

PO N01109 - None
PO N01251 - None

IV. SOURCE DATA:

Deviations from Purchase Order:

PO N01109 - None
PO N01251 - None

V. RECEIVING AND INSPECTION DATA:

Deviations from Purchase Order:

PO N01109 - None
PO N01251 - None

VI. NERVA PROCESSING:

Deviation from Fab Order:

PO N01515 - None
PO N01550 - None
Req N01874 Fill tube with .020" wall thickness was used. reworked per SDAR 40123 to provide .016" wall in seal-off area.
PO N02722: None

VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE Date ____

RESULTS: P/N 1138265-110-B S/N 880084 thru 880143 per PO N01515
P/N 1139567-10 NC S/N 880046 thru 880090 per PO N01550
P/N 1138791-3 S/N 880084 thru 880093
P/N 1138791-12 S/N 880046 thru 080050

P/N 1138791-3 and 1138791-12: The capsule walls were swaged to contact specimen button heads to improve heat transfer.

PEDIGREE DATA FORM

ITEM:

I. MATERIAL	P.O. No.	SOURCE	FORM	HEAT NO.	BILLET NO.	SIZE
Al 6061-T61						

SPECIFICATION	FORGE SOURCE	FORGING I.D.	FORGING SIZE	HEAT TREATMENT	HEAT TREAT SOURCE

II. SPECIFICATION REQUIREMENTS

CHEMISTRY	C	Mn	Fe	S	Si	Cu	Ni	Cr	Al	Ti	Mg	Co	Mo	Cb+Ta	Zr	B	OTHER
MAX																	
MIN																	

MECH. PROPERTIES	TEMP.°F	STRESS, Ksi	YIELD .2% Ksi	ELONG. %	HEAT TREATMENT	GRAIN SIZE
MAX						
MIN						

OTHER

III. PURCHASE ORDER DATA:

Deviations from specification:

V. RECEIVING AND INSPECTION DATA:

Deviations from Purchase Order:

IV. SOURCE DATA:

Deviations from Purchase Order:

VI. NERVA PROCESSING:

Deviation from Fab Order:

VII. PRE SHIPMENT TESTING - MATERIAL CHARACTERIZATION AND TEST CHECKOUT FOR TEST AGENCY USE   Date ____

RESULTS: See WANL RTS 60 for pedigree information.

P/N 1138791-2 S/N 725 thru 731 and 770 thru 776 and
P/N 1138791-11 S/N 833 thru 838: The capsule walls were swaged to contact specimen button heads to improve heat transfer.

REFERENCES

1. Standard Method for Flexural Properties of Plastics, ASTM Designation D790-66, adopted 1961.

2. Kaufman, J. G. and Knoll, A. H., "Kahn-Type Tear Tests and Crack Toughness of Aluminum Alloy Sheet," Material Research and Standards, April 1964.

3. Proposed Method of Test for Plane-Strain Fracture Toughness of Metallic Materials, ASTM Designation E399-70T.